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Unfinished Business for Physics Teachers

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IN the midst of the last depression a distinguished engineer advised us to remember that the world is not yet finished. This aphorism deserves consideration when we examine our attitude toward the art of teaching physics, whether in the secondary schools or in the colleges. It seems we are beginning to assume that this human adventure has been essentially finished and that little remains to be done except to consolidate and clarify accepted points of view and practices. It is my purpose to suggest that the possibilities for creative work in this field are many and varied and that if it is desired to have the teaching of physics regarded as a profession in the sense that law and medicine are professions, we must be prepared to make a unified and aggressive approach to the solution of a number of significant problems.

NEW EDUCATIONAL PATTERNS

In order to get an adequate impression of educational trends in the field of physics, it is necessary that the interests and activities of the profession of teaching physics be projected against the background of our rapidly changing social and economic order. Fig. 1 shows the rapid increase in the enrolments in the last three years of the secondary schools and in the first two years of the colleges and universities. This remarkable increase in enrolments has profoundly modified the educational pattern. Before 1890 it was thought that the secondary schools provided a general education and prepared a restricted number of students for college. Students without scholarly or professional interests were expected to enter upon their life work not later than graduation from the secondary school. The line of separation between the last year of the secondary school and the first year of college appeared to have some meaning. It was at least hoped that the college program even at its beginning differed from that of the secondary school. This line of separation has now largely disappeared. There has been a surge of general education into the colleges and universities which is profoundly influencing the first and second years of college work. This change has in large measure unified the problems of the last two years of the secondary school and the first two years of the colleges and universities so that the break between school and college is no longer very evident.

From Fig. 2 it is seen that there has been a marked decrease in the percentage of students enroled in physics in the secondary schools from 1890 to 1935. An even more marked decrease appears in the enrolments in astronomy. This decrease is in sharp contrast to the rapid development of physics which is superficially indicated by the membership of the American Physical Society. The contrast between this curve and those for the enrolments in physics and astronomy must serve as a challenge to teachers of physics and astronomy.

OBJECTIVES AND CRITERIONS

The educational complexities which are associated with mass education make it necessary for

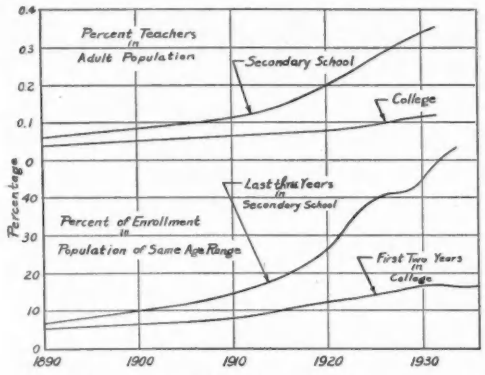

FIG. 1. Enrolments and number of teachers in secondary schools and in colleges. The lower figure shows the percentage that the enrolment is in the population of the comparable age range for (a) the last three years of the secondary school and (b) the first two years of the college. The upper figure gives the percentage of teachers in the adult population for secondary schools and for colleges. (Courtesy of R. J. Havighurst, General Education Board.)

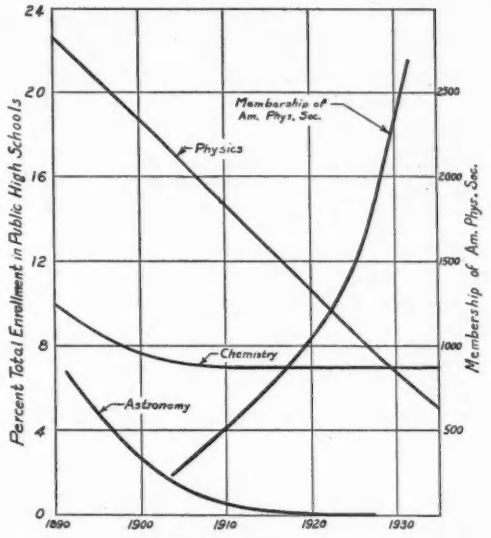

FIG. 2. Comparison of enrolments in astronomy, chemistry, and physics in the secondary schools. [Data from *Biennial Survey of Education*, Bull. No. 16 (1930) and from Sch. Life **22**, 314, 320 (1937).]

us to direct our attention again to our objectives and the criterions by which we evaluate them. It would be generally accepted that our main objective is to teach students to think clearly, to draw trustworthy conclusions from accepted facts, and to apply scientific principles to new situations. When we try to break down this comprehensive objective into parts which can be evaluated, we quickly come upon the fact that education is a social and not a physical phenomenon. The problem proves more complex than we had anticipated and we grope around with a good deal of uncertainty. To what extent we could agree upon a set of basic objectives which could be evaluated with some accuracy, is now an unsettled question. So far as I know, we physicists have not made a systematic effort to determine such a set of objectives. The Botanical Society of America has such an investigation in progress. This investigation reveals that there is great diversity of opinion among botanists with respect to the objectives for a general course in botany.[1] It may be that teachers of physics in the colleges or in the secondary schools would be found more fully in accord with respect to their objectives.

Assuming that objectives have or can be determined, we are confronted with the problem of finding criterions by which to evaluate them. If we were dealing with physical instead of educational phenomena, we would know how to proceed. We would abstract from the physical phenomena observable and invariant entities which could be fed back into the phenomena and made the basis of an accurate description of them. We would also agree quickly enough on the necessity for reproducible standards of measurement of the entities under consideration. When we come to deal with educational phenomena, many difficulties present themselves. Where standardized tests are available, the results are usually ambiguous.[2] Moreover, the same tests scored by different persons frequently show wide variations.

We must also recognize that we are training for life and not for the immediate future. In other forms of training which depend largely on skills, provision for continuous growth may be less important. The persistence of training and its permanent influence on behavior are then one of our primary problems. No critical examination of this question seems to have been made for physics, but tests have been made on

[1] Unpublished data, Clark W. Horton, Ohio State University.

[2] Horman and Hodge, J. Chem. Soc. **8**, 2071 (1931).

it in botany and chemistry. Tests based on ability to reproduce information and on ability to apply principles in botany have shown that the ability to reproduce the facts does not persist long after the completion of the course, but that the ability to apply the principles is retained for some time.[3] Such results indicate where the emphasis is to be placed in physics teaching.

Since little can be done to improve teaching until we know how to measure its quality and effects, we are here confronted with a series of important and difficult questions. We cannot answer them from the undigested impressions of immature students. We must get their answers by the use of methods of analysis not unlike those with which we are familiar in physics. The educationists have accused us of being ultra-conservative and unfamiliar with modern methods in education. Whatever may be the value of this criticism, we must be able to appraise the work we have undertaken and to justify our practices in the light of present human needs.

Professional Status of Teachers

If we are to make the teaching of physics a profession, careful attention must be given to the training and professional status of teachers both in the secondary schools and in the colleges. The conditions under which these teachers work, the compensation which they receive, and their opportunities for intellectual development and service are important factors in determining the type of person attracted to the profession. The rapid growth of secondary schools in the last twenty years has greatly increased the difficulty of supplying them with properly trained teachers. This increase is very evident from Fig. 1. In 1930 there were almost five times as many teachers in our colleges and universities as there were in 1900. The increase in the number in the secondary schools was approximately double that in the colleges and universities.

Many are now convinced that the greatest single weakness with the teaching of secondary school physics is the inadequate preparation of teachers. A large number of these teachers have not had more than a single general course in college physics, often given in a normal school where the preparation of the teacher was wholly inadequate. According to a study made by Bockstahler,[4] 18 percent of the teachers of secondary school physics in Illinois have taken no work in physics beyond a general course, and 56 percent of them have taken no more than the equivalent of two years of college physics. A study of teacher training in Ohio[5] in 1929–30 showed that 77 percent of the teachers of physics and 62 percent of the teachers of chemistry who were teaching for the first time had not had as much as 12 semester hours of physics or chemistry, respectively. A study of the preparation of teachers of physics and chemistry in 205 of the best secondary schools in Colorado[6] showed that about 15 percent of the teachers of physics and about 12 percent of the teachers of chemistry had taken less than 7.5 semester hours of physics or chemistry, respectively, in college. It is probable that conditions in other states are not very different from those found in Illinois, Ohio and Colorado.

Superposed on this meager training is the fact that many teachers of physics continue in that capacity only for a short period. A survey of the preparation of chemistry teachers in the secondary schools of Wisconsin[7] showed that 82 percent of these teachers do not continue in the work for more than five years. Several reasons contribute to this brief tenure. It is well known that many women regard teaching as an occupation for a few years before marriage and thus tend to make it a temporary job rather than a profession. Low salaries and unfavorable conditions of work also tend to reduce the tenure of teachers. Fig. 3 gives the salary distribution for inexperienced secondary school teachers in Ohio[8] for the year 1935–36 and the length of service of teachers of physics and chemistry. It is evident that these salaries are too low to attract the kind of personnel which is desired. A quotation from President Hutchins will emphasize this point:

[3] Unpublished data, Ralph W. Tyler, Ohio State University.

[4] L. I. Bockstahler, Am. Phys. Teacher **5**, 222 (1937).

[5] Earl W. Anderson and R. R. Foster, *Teacher Supply and Demand in Ohio, 1929–30* (Bur. of Ed. Research Monograph No. 11, Ohio State Univ., 1932).

[6] Unpublished data, W. B. Pietenpol, University of Colorado.

[7] J. Rogers, Chem. Ed. **5**, 1415 (1928).

[8] Earl W. Anderson, *The Seventeen Thousand High School Teachers of Ohio for the Year Ending June, 1935* (Mimeographed report, Bur. of Ed. Research, Ohio State Univ., 1937).

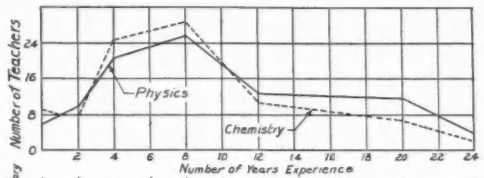

FIG. 3. Distribution of salaries of inexperienced teachers in secondary schools in Ohio and tenure of teachers of physics and chemistry in secondary schools in Ohio. (Courtesy of E. W. Anderson, Bureau of Educational Research, Ohio State University.)

"You cannot get good teachers when you show them by paying them like coolies, that you have no respect for their profession."

This tendency to withdraw from secondary teaching or never to enter it, is further accentuated by the diversity of teaching expected and the limited opportunities for intellectual development. Out of 675 teachers of physics in 1934–35 in Ohio, 9 percent were teaching physics full time, 1 percent had four classes in physics, 3 percent had three classes in physics, 19 percent had two classes in physics, and 68 percent had one class in physics. Here the implications are that a properly trained teacher of physics has little assurance that he will teach physics to any appreciable extent.

There is reliable evidence that in the last two decades there has been an overemphasis on courses in education for teachers. An investigation of this question by a committee of the American Association of University Professors showed that many teachers are of the opinion that the required hours in professional educational courses are, on the average, double the number of hours which seem adequate.[9] This committee arrived at the conclusion that "There is no reliable evidence that professional requirements have resulted in an improvement in secondary instruction at all commensurate with the amount of the requirements." A recent survey[10] of the relative emphasis on subject matter and professional courses in education in a number of teachers' colleges showed that the required courses in education consume from one-fifth to one-fourth of the student's time, whereas the required courses in science for science majors consume from one-third to one-fourth of his time. When it is recalled that secondary school teachers must expect to teach two or three different subjects, it is evident that the amount of preparation which these teachers receive in physics or chemistry is thoroughly inadequate.

If the junior colleges are looked upon as an extension of the secondary schools, we must look for the same kind of criterions for teaching in junior colleges that are now being imposed on teachers in secondary schools. As a matter of fact, requirements for certification of teachers in junior colleges are beginning to parallel those found in the high schools.[11] There is also a movement to extend educational requirements into the field of college teaching. If this movement makes headway, educational requirements similar to those now imposed on teachers in secondary schools and junior colleges will be imposed on teachers in colleges. This is a trend that college teachers of physics should not ignore. They have much to learn in this respect from the experience of teachers of physics in the secondary schools. On the other hand, we must not assume that every candidate for a Ph.D. degree in physics is inherently a good teacher of the subject and that without supervision he can teach an introductory course in physics.

The problem of teacher training is, in my opinion, the most important problem before the American Association of Physics Teachers. It is doubtful if there is a good teacher-training program for secondary school teachers of physics and chemistry in the country. Most teacher-training programs consist of disconnected educational courses superposed on truncated liberal arts programs. Too much is now being done either by specialists in the subject matter or by educationists who have little understanding of science. More intensive training in physics and allied science is urgently needed. Some of the

[9] "Report of Committee Q," Bull. Am. Assoc. Univ. Prof. **19**, 173 (1933).

[10] *Thirty-First Year Book* (Nat. Soc. of Ed. 1932), p. 334.

[11] Bull. Am. Assoc. Univ. Prof. **21**, 473 (1935).

time necessary for this training may be found by reducing the requirements in educational courses. Some of it may be found in increasing the hours necessary for graduation or by requiring a year of graduate study. Some of the states now require a master's degree to teach in a secondary school. It is probable that this trend will continue, but we must be careful to specify the quality and the content of the work for the master's degree. It must not be made of more professional courses in education. On the other hand, the subject matter courses must not be too narrow and overspecialized.

If physics is to have its proper place in our educational system, we must develop a professional attitude toward teaching of physics in the secondary schools and have less of the common practice of making it a stepping stone to something that seems better. To secure this result there must be be an increased emphasis on scholarship and professional efficiency, a better financial recognition for services, and fewer illustrations of young and poorly trained teachers fumbling with subject matter which they have never seriously studied. There must also be increased emphasis on the quality of college teaching since secondary school teachers not only learn their physics in college but largely follow the methods of instruction seen in the classrooms and the laboratories of the colleges. Definite steps should be taken by the American Association of Physics Teachers in cooperation with secondary school teachers for improving the standards of secondary school teaching in physics. We should interest the state accrediting agencies in establishing regulations which would make it increasingly impossible for secondary school teachers without the requisite knowledge of the subject matter to teach physics.

Physics and General Education

It is now generally conceded that in the last fifty years physics has exerted a very powerful influence on the intellectual, economic, and social life of the world. It becomes increasingly apparent that every graduate of a secondary school or college should have a background which gives him some familiarity with the achievement and influence of physics and its applications. We should, therefore, think clearly and intensively about the place physics is to occupy in the whole scheme of training for clear thinking and preparation for citizenship. Unity and continuity of the educational process must be the guiding principle in any excursion into this field. The contribution that physics can make to any scheme of general education then becomes a problem to which we must direct our attention. In the college area this problem is evident in recent trends toward the development of cultural and survey courses in physics with the emphasis on descriptive rather than on analytical material. In the secondary school area the same trend appears in the re-evaluation of the content of the courses in physics, in attempts to make physics more qualitative and more meaningful for students who do not continue its study. Whatever the direction in which these general or cultural courses develop, many of the questions associated with them are common to both the secondary schools and the colleges. A partial solution of these questions will tend to close up the gap between secondary school physics and introductory courses in college physics, and contribute to a better understanding of the natural problems which are common to the last two years of the secondary schools and the first two years of college.

Physics and the Public Mind

We have passed the period when leaders of scientific research think they need no social justification for their work. They no longer feel that providence placed them in fortunate situations where they are allowed to indulge their personal intellectual tastes with no thought of the practical value of their work to humanity. Perhaps some evidence of our present attitude is seen in the emphasis we are now placing on applied physics and its place in our scientific and social order. At all events, it is now evident that cooperative planning is needed in selling the whole enterprise of physics to the public. Any secondary school student knows what a chemist or an engineer or a physician does, but he knows little of the type of careers that are open to physicists.

Whatever else may be said concerning adult

education, it is easily recognized that science is imposing new demands on men and women for adjusting their thinking and their practices, and that the adult population must draw its guidance more and more from the field of science. Indeed the ultimate fate of a democratic government rests largely on the ability of its citizenry to think continuously and effectively and to settle problems on the basis of facts and logic. It is, therefore, necessary for the public to have some appreciation of rigorous thinking and some knowledge of the history of science as the record of a great human achievement. To accomplish this purpose the processes of scientific education must be continuous and life long. Emphasis must be placed on broadening the rudiments of scientific education for everyone and on stressing the means by which interest in science can be maintained throughout mature life. Hence a program of education in physics cannot be thought of as terminating with graduation from a secondary school, college or university. Provision must be made for its continuance. As teachers of physics we cannot, therefore, exclude from our interests and activities the opportunities now being opened up by the different agencies for adult education.

The possibility of a more understandable presentation of scientific work and thought is receiving increased emphasis in the public press. In *Recent Trends in the United States* a comparison is made of the circulation of scientific periodicals and Protestant religious periodicals from 1890 to 1930. This comparison shows a marked increase in the demand for popular scientific publications. There is little doubt that this demand would be further increased if more attention were given to writing scientific articles in language which could be understood by those who have not specialized in science. It is generally recognized that physics, more than any other science, has influenced our modes of thought. We must not overlook the opportunities for making its human values understood unless we are content to see physical thinking slowly choke itself to death.

More Specialized Problems

Many more detailed problems common both to the secondary school teacher and the college teacher might be easily formulated. A few are briefly summarized here to illustrate the opportunities for cooperation and mutual understanding in these fields of education.

Radio. The possibilities offered by radio broadcasting in the field of education are just beginning to be explored. Developments in this direction seem to be largely in the hands of educationists. It would seem that those who were so largely responsible for the development of the radio would not lose sight of its possibilities for instruction in the physical sciences. At least, it is now evident that the radio can serve to make dramatic announcements of new discoveries, to arouse more general interest in the progress of physics, to reinterpret what is more or less familiar, to develop scientific appreciation, and to picture personalities that have greatly contributed to physics. Even this is a great contribution to the cause of popular scientific education.

Physics museums. The importance of scientific and industrial museums in the development of an appreciation of the methods and results of the physical sciences must not be overlooked. According to the report of the International Committee on Adult Education, more than 28 American museums in 1931 included science and natural history in their fields of activity. Twenty of these museums offered courses of lectures to adults. The more progressive of these museums cooperate with the public schools. Provision for scientific museums in centers of populations where they would be easily accessible to students in the schools and colleges as well as to the general public would contribute much to the teaching of physics and do much for adult education in science.

Laboratory instruction. A further study of the purposes and methods of laboratory instruction should be made. We formulated our attitude toward laboratory instruction years ago before the great increase in college and secondary school enrolments and before the development of modern physics. Those responsible for the administration of education have frequently questioned the importance of our present practices in the laboratory. It is important to know whether we are getting the maximum out of what we are doing in the laboratories of the colleges and

secondary schools. Financial considerations, even if no better reasons are involved, will keep this problem before us and make it necessary for us to provide an answer that is capable of being checked from time to time as conditions change.

Modern physics. The effective incorporation of recent developments in physics into the introductory courses in college and secondary school physics demands continuous attention. It is clearly necessary to assimilate new material in physics insofar as it contributes to an understanding of the foundations of physics and tends to integrate the teaching program into the everyday life of the student. There is, however, a danger that the popularity of new discoveries and developments may unbalance our programs of instruction and confuse our objectives. Only continuous critical study can provide a suitable answer to this question which is common both to the colleges and the secondary schools.

Historical approach. There is a growing opinion that more attention should be given to making a historical and philosophical approach to physics. We need a history of physics, not an account of the times and places at which physical discoveries were made, but a history of the evolution of physical ideas and their relation to social and philosophical ideas. If such material were available and properly organized, it would provide a historical and philosophical approach to physics which would make possible an understanding of the development of its concepts and methods and show the way in which physics is interlocked with other forms of intellectual and social interests.

Relation of physics to biological sciences. The increasing importance of physics for the biological sciences and medicine is evident. Physical and chemical methods are becoming more and more important in these sciences. Biophysics and biochemistry are on the frontiers of scientific knowledge where great developments may be expected. Consequently teachers of physics, whether in the secondary schools or in the colleges, cannot afford to be unacquainted with the borderland between physics and biology. They must be prepared to cooperate effectively with teachers of biology.

Teaching and research. The relation of teaching to research remains a perennial question. The real problem is how to harmonize these two functions of a teacher. The general criticism that research interferes with teaching implies that the teacher becomes so absorbed in research that he neglects teaching. On the other hand, certainly the growth of the teacher demands continuous contact with scholarship and research. He must not only have an opportunity to teach but also an opportunity to participate in creative thinking, if he is to be anything more than a purveyor of a fixed body of knowledge. We must, therefore, be prepared to stimulate creative thinking in a large percentage of our students and be able to show by the record that there is no antithesis between teaching and research.

Summary

1. Social and economic changes demand that those engaged in teaching physics clarify their objectives, broaden their interests, and intensify their training in a way to insure that physics as a way of thinking be widely appreciated and increasingly effective.

2. In order that the profession of teaching physics shall remain a challenging human adventure, we must insure higher professional standards and efficiency, more adequate compensation, and larger opportunities for service and creative thinking.

3. The unity of purpose and continuity of effort required to solve the many common problems associated with teaching physics demand effective cooperation and intimate exchange of ideas between teachers of physics in the secondary schools, colleges and universities.

4. The professions of law and medicine exert strong influences through their national organizations. No great legal change takes place without the scrutiny of the American Bar Association. No movement for the regulation of medical practice or public health proceeds far without the participation of the American Medical Association. The American Association of Physics Teachers must look forward to accomplishing for teachers of physics, whether in the colleges or in the secondary schools, what the American Medical Association and the American Bar Association are accomplishing for their members.

The Natural Dimensions of Physical Quantities

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THE view has become widely accepted that what we call *the dimensions of physical magnitudes* pertain to the units employed in their measurement or to the associated numerics, and so are entirely arbitrary. With this view the writer is in accord; the unqualified term, dimensions, ought always to be understood in this sense. Where a persistent divergence of opinion exists, however, there is usually a genuine competition between alternative ideas, and it is often advantageous to recognize all of these ideas under suitable names; it was thus that the controversy between Leibniz and the Cartesians over the measure of force was resolved by assigning a place in the mechanical scheme both to kinetic energy and to momentum. As an aid to clear thought, a similar procedure seems, to the writer, to be desirable in regard to dimensions.

For the sake of definiteness, let us start from the following example. Suppose all of the linear dimensions of a piece of apparatus are increased in a certain ratio λ. Then the areas of all surfaces in that apparatus are increased in the ratio λ^2, and all volumes in the ratio λ^3. This statement has nothing to do with units; it is true whatever units may be chosen. It seems reasonable to express these facts by saying that area has the *natural dimensions* of length squared, and volume that of length cubed.

The same conception appears to be applicable to physical magnitudes in general. To be sure, the natural dimensions of a quantity will necessarily depend upon the definition of that quantity, if only because the definition specifies what quantity we are talking about. But it frequently happens that several alternative definitions can be given for the same physical quantity; in such a case, the natural dimensions of the quantity are independent of the definition that is chosen. The area of a surface, for example, or at least its numerical measure, can be defined to be the number of times that a chosen surface of unit area can be superposed upon the given surface, with the usual proviso for handling fractional parts. Or, as an alternative, we may begin by defining the area A of a rectangle of sides a and b as

$$A = kab, \tag{1}$$

where k is by definition a constant depending for its value only on the choice of units. With *either* of these definitions the natural dimensions of area come out to be length squared.

The second of the two definitions of area just given, as represented by Eq. (1), has the important characteristic that it makes the measure of area contain as factors, by definition, the measures of two lengths. For this reason Bridgman, in his book,[1] by implication ascribes the dimensions of length squared to area itself, independently of the question of units. To avoid confusion, let us call these *definitional* dimensions of area. In general, whenever the definition of a magnitude inserts into its measure the measure a of another magnitude as a factor a^n, but in no other way, we shall say that the first magnitude has *definitional dimensions* n in terms of the second.

Obviously, there may be a close connection between definitional and natural dimensions, but it is not necessary that there should be. The second definition of area, for example, as represented by Eq. (1), immediately assigns to it natural dimensions of length squared. If, however, we adopt the first definition based upon a direct comparison by means of physical superposition, the natural dimensions, although the same as before, rest upon an independent experimental fact. It is interesting to note that according to general relativity it is not true that the area of a cosmic square of edge l, as measured by superposition of a unit area, equals l^2; thus, the two definitions define different magnitudes, and only the second of these possesses natural dimensions of the square of a length. In our preceding discussion we were dealing with the nonrelativistic approximation. Corresponding considerations hold for volume.

Units and numerics, then, have dimensional relationships quite independent of both natural

[1] Bridgman, *Dimensional Analysis* (Yale Univ. Press, 1931), p. 23.

and definitional dimensions. In the so-called absolute systems the units of area and volume have dimensions the same as the natural dimensions of the magnitudes themselves. If, however, we were to choose as the unit of area the original acre, or the amount of land that a yoke of oxen can plow in a day, this would constitute an independent unit; and the ordinary dimensional equation $[A]=[L^2]$ would then be replaced by $[A]=[A]$. The acre-foot as a unit of volume used for rainfall would then have the dimensions $[AL]$.

Thus, there seem to be three distinct notions to which the term "dimensions" can reasonably be applied. The writer would suggest that all three be recognized, but that a qualifying adjective be used always with the first two, the simple term "dimensions of a physical quantity" being understood to mean, as heretofore, the dimensions or relative change-ratios of the unit and numeric that occur in the numerical measure of that quantity.

When writers have used such expressions as the "true" dimensions of a physical magnitude, they have presumably had in mind either its natural or its definitional dimensions. Confusion has been made easy by the fact that physical definitions are commonly so drawn that definitional and natural dimensions coincide whenever the natural ones are known; and, if a so-called absolute system of units is then employed, the same dimensions reappear in the units. In textbooks it would be well, in the writer's opinion, to recognize the distinctness of the three notions and to discuss briefly the relations between them. Clear thinking would thus be facilitated even if the term, dimensions, is restricted thereafter to units and numerics; the reader would not be left with an uncomfortable feeling that there is something more to the matter than has been expressed.

To illustrate further the point of view here suggested, a few other quantities will be discussed briefly.

Mechanical quantities. The natural dimensions, in the sense defined above, of mechanical quantities are obvious enough, but to disentangle them from definitional dimensions requires a little thought.

Velocity has natural dimensions, distance divided by time; but it is hard to find a sensible definition that assigns to it definitional dimensions different from these. An independent *unit*, however, is actually in use; if speed is measured in knots, the dimensional equation $[V]=[L/T]$ is replaced by $[V]=[V]$.

Force, on the other hand, is capable of treatment in several different ways, at least in macroscopic physics. For example, starting from the qualitative definition of force as directed accelerative action, one might postulate (1) that a body acting mechanically, such as a compressed spring, when applied under given circumstances to different bodies in succession, exerts the same force upon all of them, and (2) that the forces due to several bodies acting simultaneously are equivalent to their vector sum acting alone (a proposition which has to be laid down in the form of a postulate or definition in any case). These postulates furnish a sufficient basis for the measurement of force, two forces being compared, for example, in terms of the number of similar and equally compressed springs that must act simultaneously to equilibrate each of them; the postulates constitute, therefore, an adequate definition of force. Mass can then be defined as the reciprocal of the acceleration produced by unit force.

It will then be found that, if all masses are changed in the ratio μ and all accelerations in the ratio α, all forces are changed in the ratio $\mu\alpha$; from this it follows that force has natural dimensions in terms of mass, length, and time equal to mass times acceleration. With the usual definition of force, these are the same as the definitional dimensions and follow directly from the definition alone; but with the definition described above, the natural dimensions of force arise partly from the definition of mass and partly out of an additional experimental fact.

Other mechanical magnitudes can be treated in a similar manner.

Temperature. Suppose that in a rarefied monatomic gas in equilibrium we change all of the molecular velocities in a certain ratio, and likewise all of the molecular masses in another ratio. Then, the absolute temperature of the gas, as measured by a thermometer immersed in it, will be changed in the same ratio as are the molecular energies; for, according to kinetic theory, temperature and the mean translatory energy of gas

molecules are proportional. It seems to follow unquestionably that temperature has the natural dimensions of energy.

A simple absolute definition of the *unit* of temperature would be, accordingly, to define it as that increase in temperature which raises the mean translatory energy of a gas molecule by 1 erg. (This is an old suggestion.) Other thermal magnitudes then have simple mechanical dimensions; entropy, being calculable as energy divided by temperature, is dimensionless, like the number of molecules in a given body, and so is the gas constant, including the Boltmann constant k; whereas, specific heat has the dimension of the reciprocal of a mass. For practical purposes, however, a minute fraction of the absolute unit would have to be employed, for the latter would equal about 7.3×10^{15} centigrade degrees.

The *ordinary* units of temperature, on the other hand, have a special dimension of their own, since the freezing and boiling points of water are independent of the units chosen for mass, length, and time. For practical purposes, furthermore, it seems to the writer that the most convenient procedure is the familiar one of treating temperature as a dimensionally independent magnitude and allowing quantities such as entropy and specific heat to have suitable dimensions in terms of it in addition to other quantities.

Angle. Changing the linear dimensions of a body has no effect upon any angles occurring in it; hence, angle has natural dimensions zero in terms of length. In fact, angle seems not even to have an independent natural dimension of its own, for we cannot possibly change *all* angles in the same ratio, the sum of those about a point remaining obstinately equal to 2π. Euclidean space is stretchable linearly but not rotationally.

On the definitional side there are well-known alternatives. Since the subject is not discussed either in Bridgman's book or in Birge's article,[2] the following summary of the situation as viewed by the writer may be of interest.

If an angle θ, or at least its measure, is defined as the ratio of subtending arc to radius, then θ is clearly a number as pure as π. The unit is thereby automatically fixed as the radian, but in strict logic it does not require mention; on the basis of the definition stated, to speak of an angle of 3 *radians* is really as tautological as to say that the ratio of electron to proton mass is 0.00054 *unit.* If degrees are used instead of radians, some sort of indirect statement must be understood; perhaps a parallel case would be the statement that the ratio of electron to proton mass is 0.054 *percent.*

The alternative definition is that an angle is the opening or space, or something of that sort, between two intersecting lines. This definition gives to angle an independent definitional dimension, and it requires the adoption of an arbitrary unit, which then has an independent dimension entering with the angle into physical equations.[3] The complete expression for the work done by a torque L in turning through an angle θ, for example, is now $W=cL\theta$, in which the constant c depends on the unit used for θ and has the dimension of the reciprocal of angle. If, nevertheless, using radians, we write $W=L\theta$, the symbols do not fully exhibit the dimensional relationships; a factor equal to unity has disappeared from the equation and has carried dimensions out with it. An analogous example is the disappearance of charge from one side of the equation when, using atomic units, we write for the charge on a body containing an excess of N electrons, $Q=-N$.

In practice, the simplest procedure seems to be to ignore the complications introduced by the second and, perhaps, more satisfying definition and to treat θ in physics as a pure number whose unit represents a radian.[4] Then, if in a particular case we wish to employ a measure θ' in terms of some other unit containing r radians, we merely insert $r\theta'$ for θ in the physical formula; that is, we convert in the usual way to radians.

Electrical and magnetic magnitudes. The effect of changes in the dimensions of apparatus upon electromagnetic phenomena is easily calculated. There is a question, however, whether in making such changes the physicist alters *all* of the physical distances that are involved. In present-day theory, for example, the charge on an

[2] Birge, Am. Phys. Teacher **3**, 102 (1935).

[3] Cf. Brinsmade, Am. Phys. Teacher **4**, 175 (1936).

[4] Cf. Webster, Science **46**, 187 (1917).

electron is a simple invariant. Now, it may be that this charge really does represent an unalterable natural constant; but the possibility cannot be ruled out that the electron may, after all, possess something equivalent to an internal structure, and if it does, we cannot say in advance how the charge would be affected by an alteration of the scale of this structure. Thus, it must be admitted that we do not really know the ultimate natural dimensions of electrical charge in terms of mass, length, and time.

The same thing can be said about all electrical and magnetic quantities. Perhaps it has been considerations of this sort, or analogous ones in regard to the ether, that have led so many writers to say that the "dimensions" of dielectric constant and of permeability are unknown. It appears that we may agree with them provided ultimate *natural* dimensions are meant (and provided electromagnetic quantities are defined in such a way that dielectric constant and permeability are not pure numbers.)

In choosing units for electromagnetic quantities, accordingly, there are only definitional relationships to serve as a guide, in addition to considerations of practical convenience.

Epsilon Aurigae, Colossus Among Stars

A Story of Cooperative Research in Photometry, Spectroscopy, and the Theory of Gases*

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AND
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SWINGING out of the zenith and down into the northwest after sunset as the spring comes on, is the constellation of Auriga, the Charioteer (Fig. 1). Dominated by the brilliant Capella (the She-goat), the other stars in the group are inconspicuous and the constellation as a whole is unfamiliar to most of us. A few degrees southwest of Capella is the third-magnitude star of our present interest. Fifth in brightness of the stars of the constellation, it is unnamed except to denote that fact—epsilon. This label was applied in 1603 by the German astronomer Bayer and, although there have been many changes in nomenclature and not a few alterations in intensity of the stars themselves since that time, there is no reason to suppose that the apparent visual magnitude of epsilon Aurigae, namely 3.1, has undergone any permanent change during historical times.

The first person to suspect that this star was unusual in any way was a German pastor, Fritsch, in Quedlinburg. In 1821 he noticed that epsilon Aurigae was fainter than normal, and he communicated this observation to the astronomer Bode. No one else had noticed anything unusual, however, and the observation of Fritsch was promptly forgotten. Toward the end of the year 1847, another German astronomer, Heis, independently noticed that the star was unusually faint. Since then, many observers have recorded the light of epsilon Aurigae, and in 1903, after many years' discussion as to whether it was an irregular or regular variable, the present director of the Potsdam Observatory, Ludendorff, assigned it to the latter class with a period of 27.1 yrs.

For about 25 years the light of epsilon Aurigae is nearly constant and of magnitude close to three. Then it begins suddenly to get fainter, declining steadily in brightness for an interval of 200 days. By this time its magnitude is about four. For nearly a year (360 days) it remains *constant* at this intensity, then during another

* The complete technical discussion of this star was published under the title "The Interpretation of Epsilon Aurigae" by G. P. Kuiper, O. Struve and B. Strömgren, in the December, 1937, issue of *The Astrophysical Journal* (University of Chicago Press). After an informal presentation of the results at the University of Chicago, Professor Lemon suggested that the subject would be of considerable interest to physicists if the story of epsilon Aurigae could be told without the technical astronomical details which are required to establish every step of the discussion. To him the original authors are indebted for the form of presentation and the style of the present article.—O. STRUVE.

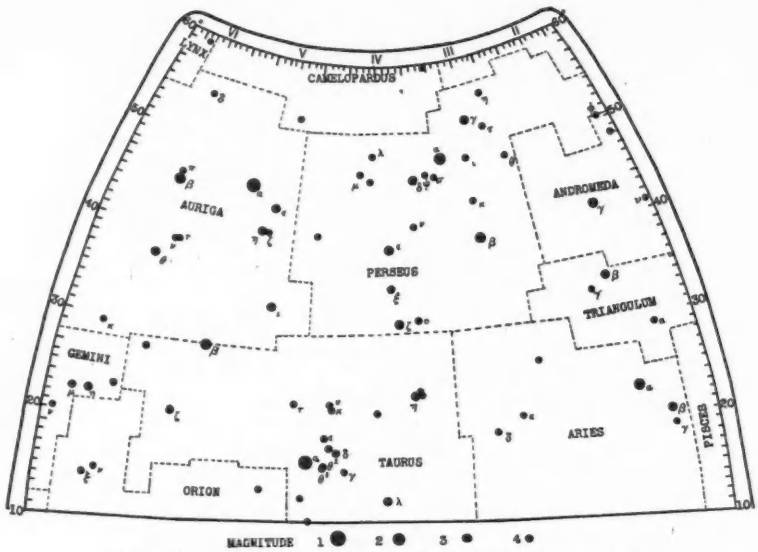


FIG. 1. The northerly constellations in springtime early evening.

200-day interval steadily increases in brightness until the normal magnitude of 3.1 is reached. The light thereafter remains approximately constant for another quarter of a century. The latest weakening of the light took place during 1929–30, or about 109 years since the observation of Fritsch. During this interval the star had completed four full periods.

Now, except for the length of its period of variability, there is nothing at all remarkable in a star that behaves as we have just described. There are literally hundreds of stars of varying visual luminosity and of all sorts of periods, usually much shorter. Commenting on the long period of epsilon Aurigae, Miss Agnes Clerke[1] in 1905 wondered "whether future minima will honor the cheques of calculation as they fall due," and "whether epsilon Aurigae may still evade the law of order that it has temporarily obeyed." By repeating its regular minimum again in 1929–30, the star established beyond doubt its exceptionally long period of regular variability, giving added force to another comment of Miss Clerke's made 20 years before that date. She said,[2] "Should Dr. Ludendorff's regularization of them [the unusual pair of objects constituting the star] be verified by future observation, their 27-year period will be by far the longest that can be ascribed to any form of stellar light change, and it will be quite important to correlate with it, if possible, the star's period of orbital revolution. *There is perhaps no object in the heavens of more pregnant interest than this spectroscopic binary.*"

Prescience such as this is rare, even among astronomers. Miss Clerke exhibited it on more than one occasion. It is to be found only among the most thoughtful, careful, and widely informed scholars in any field.

The Yerkes Observatory has participated in the solution of many astronomical problems; but, during the forty years of its existence, never has it encountered more difficulty in the guise of apparent simplicity than in its efforts to make the correlation of photometric and spectroscopic data for this star. Indeed, no other problem has been so completely identified with the history of the Observatory during that same period. On November 29, 1900, E. B. Frost, who later was to succeed G. E. Hale as its director, obtained his first spectroscopic observations of this star with the 40-inch refractor. This photograph was obtained more or less by chance—during the course of a program of

[1] A. Clerke, *Systems of the Stars* (A. & C. Black, London, ed. 2, 1905), p. 105.
[2] Reference 1, p. 192–3. The italics are ours.

observations that included a large number of stars. However, this first plate showed a spectrum consisting of unusually strong and crisp absorption lines unlike those observed in many other stars, and for this reason Frost decided to keep epsilon Aurigae permanently on the observing program of the Bruce spectrograph attached to the 40-inch refractor. By 1932 several hundred spectroscopic observations had been secured.

During all this time, however, every attempt to explain and to correlate the observed facts of the light curve through the two minimums that had occurred while the spectroscopic data on the orbital motion were being acquired, with the spectroscopic data, had proved entirely abortive. During the same interval, a number of other great observatories—Berlin, Mount Wilson, Madison (Wisconsin), and others—had entered the lists and been humbled in the same attempt.

About three months ago the Yerkes group, recently augmented by two distinguished young astronomers, Gerard P. Kuiper, formerly of Leiden, and Bengt Strömgren, from Copenhagen, again attacked the problem. A greater versatility of offensive was now available. Whereas the 1932 team was composed of three spectroscopists, Frost, Struve, Elvey, the 1937 group had a much greater diversity of background. Kuiper devoted himself to the photometric data and its implications, Struve to the spectroscopic, and Strömgren's function was to place a sound theoretical foundation under the whole structure, tying together, if possible, the divergent hypotheses

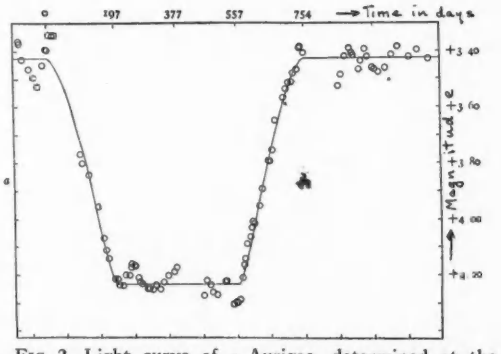


FIG. 2. Light curve of ε Aurigae, determined at the Washburn Observatory of the University of Wisconsin. The abscissas are days and the ordinates are stellar magnitudes.

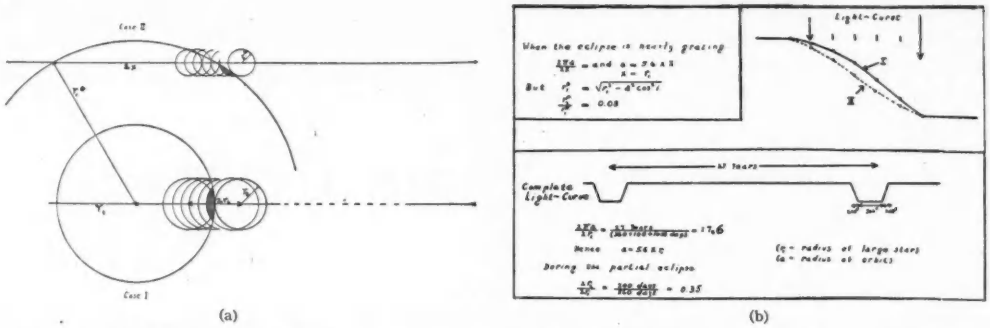
separately suggested by the photometric and the spectroscopic observations. Here was carefully planned, cooperative research, thoughtfully designed strategy, carried on by a truly cooperating group where each individual represented a special field.

This concerted attack has proved swiftly successful. The mystery of epsilon Aurigae, which puzzled astronomers for nearly forty years, has been solved, and the heterogeneous mass of contradictory facts has, as if by magic, been arranged into a single harmonious picture. What had appeared as a hopeless tangle only a few months before has now taken the form of a beautiful theory. So convincing and so accordant have the observations shown themselves to be when interpreted in the light of these new hypotheses, that Strömgren was not faced with the necessity of verifying the hypotheses proposed by Kuiper and Struve. He was able to consider the hypotheses as firmly established by the observations. With this assurance back of him he was able to show how physical theory accounts for the hypotheses themselves.

Let us now look at the simple photometric and spectroscopic facts presented by this twinkling shaft of light—to learn more in detail how the inconsistencies between them are more apparent than real and how, by this very fact, there is revealed a celestial system of magnitude and character hitherto undreamed, even by astronomers, a system at the present moment unique among the hundreds of thousands of stellar systems of which the dynamics and physical characteristics have so far been investigated.

First of all, the periodic change in the light intensity of epsilon Aurigae, which we described in detail above, is typical for an *eclipsing* double star. We know hundreds of other stars which are in reality systems consisting of two suns revolving around one another in elliptical orbits. If the plane of this ellipse is properly oriented, namely, in such a way that it passes through the earth, we observe the periodic eclipse of one star by the other. If both components of the star emit equal amounts of light, a total eclipse would produce a diminution of light during eclipse to one half its normal value.

In the case of epsilon Aurigae, we are dealing with a variation of light which strongly suggests



(a) (b)

FIG. 3. (a) Approximate solution for the radii of the components of an eclipsing binary. In Case I (lower left) the inclination is 90° and the eclipse central. The lower part of (b) shows how the ratio of the radii may be derived. Case II (upper left) refers to an inclination of the order of 65°, and the computation of the radii is given in the upper left part of (b). The shape of the light curve, as shown in the upper right-hand section of (b) can be used in ordinary stars to choose between different inclinations. When the eclipse is central $2\pi a/2r_1 = 17.6$; when the eclipse is grazing $2\pi a/2x = 17.6$.

that there is such an eclipse every 27.1 years. We suspect epsilon Aurigae to be a double star. So long a period would also suggest either an unusually wide separation of the two components of the star or else an excessively slow rotation about their common center of mass combined with great remoteness from our earth, thus preventing resolution of the two stars. Since the highest available resolution fails to show a visual double, we must accept the latter hypothesis of a close spectroscopic binary and then use the Doppler effect in the light of the two components to test our suspicions and to provide additional orbital data.

Red shift of spectral lines in a star implies recession from the observer; blue, approach; and if the star is really a binary, the velocity shifts will vary periodically. Conversely, if the velocity shift of the lines is always the same, the star is not a binary.

Now, it appears that the shifts in this star actually do vary. In 1899 when the work was started, the star was receding with a speed of about 10 km/sec. Between 1905 and 1920, the lines shifted in the opposite direction, towards the violet, corresponding to an approach at a rate of about 10 to 15 km/sec. After 1920 the star again receded, reaching a speed of nearly 20 km/sec in 1925. Since then, the speed has again decreased and it is now one of approach. The entire cycle testified to by the radial velocity curve is 27.1 yrs—*exactly the same as that shown by the variation of the light.* We conclude that epsilon Aurigae is really a binary. So far everything we have observed is in beautiful agreement.

Now the spectra of double stars are usually "doubled" spectra. By this, we mean merely that each luminous component of the star has its own spectrum; and, as the two sources of light rotate about their common center, the lines of one source will show approach to the observer while those of the other show recession, and vice versa. At times halfway between these phases when the motion of the components is at right angles to the line of sight, there is no shift of spectral lines of either star. It is at such times that we should expect to see the photometric results of an eclipse, provided we lie close enough to the plane of the stellar orbits. Now, in epsilon Aurigae we *observe only one set of absorption lines.* All the light which is recorded on our spectroscopic plates comes, therefore, from but one component of the binary. Had the other component been as bright as this one, it would also have registered a set of absorption lines, and these would have shown the opposite variation in velocity shift.

Thus we approach the first stage of the puzzle. The spectrum tells us that only one component of the binary is bright. The other must be relatively dark. But the observations of the eclipse give us a diminution in light during total phase from magnitude three to magnitude four; that is, the light during the eclipse is cut almost exactly in half. From the constant intensity of the light during its minimum, we know that the

eclipse *must be total* and not partial. This implies that the two components have *equal* amounts of light, since only in that case can we be left with half the light when one component is completely blocked out by the body of the other component.

The spectrographic observations say, in short, the two stars must be very different in luminosity; the photometric observations, on the contrary, say the two stars must be very similar in luminosity.

This contradiction cannot be explained away by errors in the observations or by the uncertainty of computations. All these tricks of the trade have been tried. No simple solution to the dilemma can be found. This was especially surprising and annoying, because, taken separately, the arguments of the spectroscopist and those of the photometric worker are irreproachable. They have been applied individually and collectively to hundreds of other stars in the past. Heretofore they have never failed to yield consistent results.

We are compelled to make a more detailed study of the star in order to clear up this mystery. Let us look first at the variation in light. Fig. 2 shows some of the actual observations which were secured by C. M. Huffer and Joel Stebbins at the University of Wisconsin. A more schematic representation is shown in the bottom diagram of (b) in Fig. 3. The abscissas represent time and the ordinates the brightness of the star. It will be noted in Fig. 2 that throughout the minimum light the curve is *flat*. This constitutes our evidence that the eclipse must be total, the entire disk of one component being hidden. If the eclipse were partial, so that a portion of the disk remained unobscured, the bottom of the light curve would be curved.

We next notice that there is *only one eclipse* during the 27-yr period of revolution of the binary, a period to which the spectroscopic evidence also attests. Let us, for convenience, designate the two components of the star by the letters F and I. If the two components were alike in size, we would expect two eclipses: one when component F is hidden behind I and another when I is hidden behind F. Since only one eclipse is observed, we infer that the two stars are not alike. Only if one star is very much larger than the other may this result of but one effective eclipse per revolution be possible.

Next, we will attempt to find the relative dimensions of the two components. Let us designate by a the radius of the 27-yr orbit (which, for simplicity, we shall assume to be a circle). Then we know that it takes 27 yrs for component F, say, to travel the length of the circle $2\pi a$. But the center of component F remains hidden by the disk of component I for only about $100+360+100$ days. From these facts, we can derive the *relative* sizes of the component stars and their orbits, provided we assume that *the eclipse is central*. If component F, having a radius r_2, heads straight towards the center of component I (Fig. 3, Case I), having a radius r_1, then it is clear that

$$2\pi a/2r_1 = 27 \text{ yrs}/(100+360+100) \text{ days} = 17.6.$$

Hence $a = 5.6r_1$. But we also know that from the moment when the edge of the component F just begins to disappear behind component I until the moment when the entire disk of F is eclipsed by I, 200 days must elapse. Hence we find $2r_2/2r_1 = 200 \text{ days}/560 \text{ days} = 0.35$. Component F is, therefore, only about one third as large as component I.

Of course, we have no way, as yet, of telling whether the eclipse is really central or not! It may be more nearly grazing, since the orbit may not lie exactly in the same plane as the earth. In that case, we would have to modify our computations, as is shown in Fig. 3, Case II. The cord $2x$ is now equal to what we formerly called $2r_1$, and the new radius of component I becomes even larger, while the radius of component F becomes still smaller.

Now the conventional method for distinguishing whether or not an eclipse is central consists of a rather intricate study of the shape of the light curve. The two enlarged sections of the light curve for Cases I and II shown in Fig. 3 (b) upper right, illustrate the method. The difference arises from the fact that the area of component F,

TABLE I.

	COMP. I, r_1	COMP. F, r_2
Central eclipse	$0.17a$	$0.06a$
Intermediate	$0.36a$	$0.03a$
Grazing eclipse	$0.50a$	$0.02a$

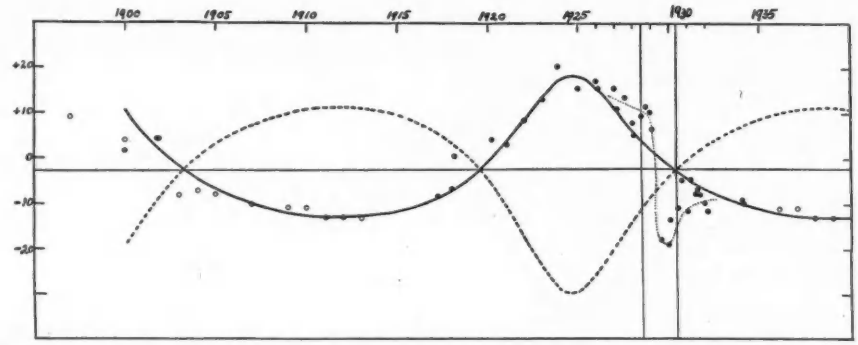


FIG. 4. Velocity curve of ϵ Aurigae. The abscissas are years and the ordinates are radial velocities in kilometers per second. Only one component can be measured and the full line shows the representation of the observations by means of an elliptical orbit having an eccentricity of 0.33. The dotted curve shows the corresponding velocities of the invisible component of ϵ Aurigae which have not been observed but which may be inferred from the ratio of the masses. The departures of the observations during the time of the eclipse 1928–29–30 are caused by the blending of the absorption lines of the *F*-component with spectral lines which are produced during the passage of the light of the *F*-star through the ionized layers of the *I*-star.

which is cut off by component *I*, varies in a different manner with the time, depending on whether the radii of the components are in the ratio of 1 : 0.08 (Case II) or in the ratio 1 : 0.35 (Case I).

Since Kuiper found that this method could not be employed in the case of epsilon Aurigae because of the very great disparity of the values of r_1 and r_2, and also because of the unavoidable errors of the observations, it was necessary for him to develop a new method. There is first constructed a table (Table I) listing several corresponding values of r_1 and r_2.

It does not seem likely that any binary could exist where one component had a diameter equal to one-half the radius of the orbit. Such a star, if it could come into existence at all, would rapidly be broken up by the tidal actions. Accordingly, we may disregard the case of the grazing eclipse.

The next step in Kuiper's analysis is to choose between the case of a central eclipse and an intermediate eclipse. For this purpose he makes use of the Doppler velocity shifts of the absorption lines of the *F*-component. Fig. 4 shows the measures of the radial velocity plotted against time as the abscissa. The curve is not quite symmetrical; it is rather flat near minimum (when the velocity indicates approach) and is steep near maximum. A simple sine curve would indicate circular motion of the *F*-component. The departures from a sine curve measure the ellipticity of the orbit. Now, it is obvious that since the Doppler shift measures that component of the velocity of the *F*-star which is in the line of sight, the maximum and the minimum velocities give us approximately the true orbital velocity of the *F*-star.[3] Indeed, when the velocity is all in the line of sight, we observe the maximum (or the minimum) in our velocity curve. This orbital velocity is approximately[4] 15 km/sec.

Now, if it takes 27.1 yrs for the star to go once around this orbit at a rate of 15 km/sec, the entire length of the orbit is

$$15 \times 27.1^{y} \times 365^{d} \times 60^{m} \times 60^{s} = 1.3 \times 10^{10} \text{ km}.$$

This orbit we found previously to be equal to $2\pi a$, and thus we can express the radii of the two stars in Table I in kilometers. We encounter here another small complication: the velocity shifts which we measure on the spectrographic plates register the motion of star *F* around the center of mass of the system *F* and *I*. What we really want is the length of the orbit of *F* around *I*.

If the component *I* is so massive that the

[3] Note the displacement of the line of symmetry of the velocity curve from the zero on the *Y*-axis—denoting an approach of the system as a whole of about 3 km/sec.

[4] Strictly speaking, this is true only when the earth lies in the plane of the orbit, in other words, when the eclipse is central. When the eclipse is intermediate or grazing, it is necessary to correct the observed velocity by a small factor which depends upon the angle of the inclination of the plane of the orbit to the line of sight. This can be done without difficulty, and we shall not bother to explain it in detail.

center of mass of the I and F system is near the center of I, then we can simply write $2\pi a = 1.3\times10^{10}$ km. But if I and F are of equal mass, then the radius of the orbit of F around the center of mass is only one half of the radius of the orbit around I. Hence, in that case, since a is the distance between F and I, and not the radius about the center of mass,

$$2\pi a = 2\times1.3\times10^{10} \text{ km}.$$

We cannot be sure which assumption to make until we know the ratio of the masses of star F to star I. This information can be obtained with the help of the so-called "mass-luminosity relationship,"[5] well known to astronomers.

Kuiper then uses an accurate curve, recently established by him, which relates the mass of a star to its total luminosity. The procedure is first to adopt an arbitrary value for the ratio of the masses of star F to star I. For example, he assumes that the mass of F is equal to the mass of I. Then the corresponding value of the radius of the orbit would be, as given above,

$$a = 2.6\times10^{10}/2\pi \text{ km},$$

and from Table I, *assuming a central eclipse*,

$$r_2 = 0.06a = 0.06\times2.6\times10^{10}/2\pi = 2\times10^{8} \text{ km}.$$

Thus the radius of the star is found. Consequently, we can determine the area of its surface:

$$\text{Area} = 4\pi r_1^2 = 5\times10^{17} \text{ km}^2.$$

But the spectrum of the F-component of epsilon Aurigae has been observed; and, from the distribution of light in it as a function of wavelength, we can determine its temperature. In fact, we always designate a star having a spectrum similar to that of epsilon Aurigae as belonging to spectral class F (hence the designation of the component); and we know that the temperature of an F-star is about 6500°K. If we know the temperature of a body we can, by comparing it with a black body, find its surface brightness; and if we multiply the latter by the area, we find the total amount of energy radiated by the star; that is, we arrive at a value for the luminosity.

At the same time, once we have made a guess concerning the mass ratio, we have also fixed the total mass of the F-star. As a matter of fact, the total mass of the system of $F+I$ is given by Newton's law of gravitation. We do not have to guess at this: only for a particular value of the masses will one star move at a definite distance about another with an orbital speed of 15 km/sec. Now, when the mass of the F-star and the total luminosity are independently determined in this manner, we can enter the values in the mass-luminosity diagram and see whether the point with the two coordinates so obtained falls upon the general curve. If it does, all is well. If it does not, we infer that our guess concerning the mass ratio was incorrect. A few trials with different mass ratios are sufficient to settle the question. Once that is done, we will know the total mass and the corresponding total luminosity of the F-star. We find that on the assumption of a central eclipse the luminosity of F would be almost a million times greater than that of the sun—which is quite unreasonable; we have reason to believe that no F-star could exist with such an enormous luminosity.

But for a suitably placed intermediate eclipse the luminosity comes out more reasonably—about 6×10^4 times greater than that of the sun, and the corresponding mass is about 40 times that of the sun. Such stars, though unusual, are known to exist in the universe, and we therefore do not regard the F-component of the binary as particularly unusual.

Incidentally, the masses of the F- and the I-components justify the assumption first made and come out to be almost equal; the latter is slightly less massive. At any rate, we know its mass, and consequently, from the mass-luminosity curve, we know that it, too, must radiate about 6×10^4 times as much energy as does the sun.

[5] First suggested many years ago by Eddington, this relation expresses the fact that all stars having the same mass emit very nearly the same *total amount* of radiant energy. Some stars may be small while others are large; but it is an established fact that the small stars are correspondingly hotter than the large stars, provided their masses are all the same. For example, all stars having a mass equal to that of the sun radiate the same total amount of energy as does the sun. If the star is large, it must be relatively cool so that its surface brightness (per unit area) will be correspondingly smaller than that of the sun. Such a star will emit most of its light in red waves, while the sun is rich in yellow and blue waves. If a star contains 150 times as much mass as does the sun, it radiates approximately 6×10^5 times as much energy as does the sun. If the mass of the star is 15 times that of the sun, the total energy radiated by it is roughly 10^3 times that radiated by the sun.

Now we come to the really astonishing result obtained by Kuiper. Since the *I*-star, as we have seen, is very much larger than the *F*-star (for an intermediate eclipse $r_1 = 0.36a = 12r_2$), the surface area of the *I*-star, which is proportional to r_1^2, *is about 144 times greater than the surface area of the F-star.*

Stefan's law of radiation tells us that the energy radiated by unit area of a black body is proportional to the fourth power of its absolute temperature. Hence, knowing the total energy and total area sending it forth, we are able to determine the temperature of the *I*-star. With the help of somewhat more accurate data than those given above, Kuiper finds for the *I*-star a temperature of only about 1300°K! This is an exceptionally low temperature for a star. From Wien's law we infer that the maximum amount of the radiation comes approximately at wavelength 20,000A, which lies in the most extreme infra-red region of the spectrum where the human eye is entirely blind, and where even the best infra-red photographic emulsions are quite insensitive.

Consequently, the *I*-star is *infra-red* (hence the letter *I*), and it cannot be seen or photographed. There is, however, some hope that it can be observed by means of instruments of the radiometer type. Thermocouples have been successfully used by astronomers for the measurement of the total heat radiation of stars and planets. C. F. Rust of the Yerkes Observatory is now engaged in developing a thermocouple and a method of using it to measure the radiation of the *I*-component of epsilon Aurigae.[6]

We are now ready to face the second stage of the puzzle. The eclipse we have seen is total although not central. While it is in progress every part of the *F*-star is covered by the *I*-star. Hence, during the eclipse, all observed light must come from the *I*-star. But we have also found, on the other hand, that the *I*-star *has no visible light;* its radiations are nearly all in the extreme infra-red.

Related to this stage of the puzzle there is yet another puzzle. While the eclipse is in progress the observed light is *all yellow*—just like that of a normal *F*-star. In a real *total* eclipse the yellow light should have been extinguished.

Finally, we observe in the spectrum that even during the total phase of the eclipse all *spectral lines* of an *F*-star of temperature 6500°K are visible. They, too, should be extinguished.

For a while the problem looked rather hopeless. Three major contradictions and several smaller ones had been detected, but no simple explanation could be found. Numerous conferences and discussions were held among the three cooperating Yerkes astronomers. Finally, it was decided to retrace all steps of the analysis and to check *every assumption* and *every deduction.* In doing this, it was found that while all steps were sound and logical, all contradictions centered upon one assumption: during the totality of the eclipse the light of the *F*-star is completely blocked by the enormous body of the *I*-star. This assumption had seemed logical enough—no astronomer had ever thought anything different—had never dreamed of there being *transparent* stars. Certainly no star could ever be seen through even a dwarf star like our own sun. In epsilon Aurigae we are dealing with an infra-red star which has a diameter roughly 3000 times larger than that of the sun. A large part of the solar system, as far out as Saturn, could be easily accommodated within the bulk of the *I*-component. The *F*-star is, as we have seen, from 10 to 20 times smaller.

It is easy to see that all difficulties would be removed if we assume that the *I*-star is semi-transparent, so that the *F*-star would shine right through it during the eclipse. Startling as this may appear, such an assumption is by no means unreasonable. The *I*-star is infra-red, and no infra-red stars have formerly been investigated. The fact that the hotter and visible stars are opaque proves nothing when we deal with an infra-red star. Indeed, the opacity of stellar material is, to a large extent, caused by the processes of ionization in the stellar atmospheres. In a normal hot star the temperature of the gas is so high that many atoms are broken up into

[6] As we write this, we learn that J. S. Hall of Sproul Observatory, Swarthmore College, has trained a photoelectric cell, which he has been using on other stars for several years, upon epsilon Aurigae. He has confirmed by direct observation the existence of the *I*-star; and Kuiper, using the small excess of infra-red in the total light found by Hall, has calculated the physical properties of the two components with results in excellent agreement with those of this paper. See Hall, Astrophys. J. **87**, 209 (1933). Still more recently, three Harvard astronomers, R. M. Emberson, R. Loevinger and T. E. Sterne, have confirmed the existence of the infra-red component by means of radiometric observations with a thermocouple.

ions and free electrons. It is the latter, flying about without constraint through the gas, that cause it to be cloudy and opaque. But the *I*-star is so cool that it cannot effectively ionize the atoms of its own constituent gases. The atoms remain intact and the star is more or less transparent.

It is at this point that Strömgren enters the picture. As the *F*-star revolves around the *I*-star, the outer layers of the latter are not much more distant from the *F*-star, with its temperature of 6500°K, than they are from their own (*I*) star's relatively cool center.

Strömgren has applied the theory of gaseous ionization to take account of the action of the *F*-star upon the *I*-star. The *F*-star with its high temperature radiates a large amount of high energy ultraviolet radiation. This light enters the *I*-star, is immediately absorbed by the gases, which are ionized thereby. Free electrons created in the outer layers of the *I*-star thus produce therein a certain degree of opacity. Thus the visible light of the *F*-star is reduced to about one-half of its normal amount.

The crucial test of Strömgren's idea is to see whether it can explain the flat minimum of the light curve. It might be expected that since the light path of the *F*-star through the *I*-star follows a series of chords of increasing and then decreasing lengths, the light curve would be rounded at minimum. But the essential point here is that the ultraviolet light of the *F*-star, which gives rise to photo-ionization in the *I*-star's atmosphere, is quickly absorbed in a relatively thin outer shell on that side of the *I*-star which is adjacent to the *F*-star. The thickness of this shell is nearly constant over the entire hemisphere. Since the partial opaqueness for visible light is localized within the same shell, the diminution in visible light during totality of eclipse remains practically constant.

In effect, the *I*-star has a layer on its hemisphere directed toward the *F*-star which is similar to the Kennelly-Heaviside layer in the atmosphere of the earth. The analogy is rather striking: our sun is a star whose temperature is roughly 6000°K, and our own atmosphere is normally not unlike the cool and un-ionized mass of gas in the *I*-star. Even the distances involved are not strikingly different. The *F*-star, as seen from the terminator (edge) of the *I*-star would appear as a disk with a radius of about 1.8°, or seven times as large as the sun seen from the earth. The ionization will be much stronger in the *I*-star, and the opacity much greater. In the earth's atmosphere the opacity of the Kennelly-Heaviside layer to visible light is negligible; in the *I*-star it is important. These are differences in degree but not of kind.

Since this is the first time that anything like this phenomenon has been found in a celestial body, it behooves us to be cautious. So far our evidence has all been indirect. The only datum of observation which has been used to determine the opacity of the ionized layer of the *I*-star is the depth of the light curve during total eclipse.

There is, however, another important test which we can make in order to prove or disprove the theory. If the light of the *F*-star shines through many millions of miles of gas belonging to the *I*-star, should we not expect to observe some spectral absorption lines produced by this gas?

The numerous spectrographic observations made during eclipse permit us to answer this question immediately. *The lines produced in the I-star are present.* They correspond to a spectrum that is similar to, but not at all identical with, the spectrum of the *F*-star seen through the semi-transparent screen.

Should we have expected the lines normally observed in a very cool star? No, of course not! The lines observed in the gas of the *I*-star are produced by the radiation of the *F*-star; and, within the super-Kennelly-Heaviside layer at least, we shall expect to observe lines normally due to radiation of that temperature, such as those of ionized elements—iron, titanium, calcium, and many more. In the un-ionized layer directed away from the *F*-star many lines of cool gases could be expected. Here the resonance lines of neutral elements should be especially strong, because they require no high temperature for their excitation. Indeed, the resonance lines of neutral sodium, D_1 and D_2, at least, are tremendously strong in the spectrum observed during the eclipse. From the super-Kennelly-Heaviside layer we get many of the absorption lines of the *I*-stars, which are identical with lines of the same elements belonging to the *F*-star *except for their Doppler displacement.* Because of the fact that, fortunately, the *I*-star rotates on

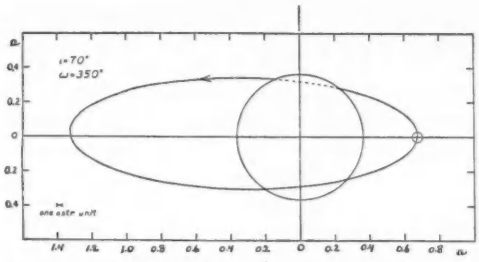


FIG. 5. The orbit of ε Aurigae as seen projected upon the background of the sky. The large circle represents the *I*-star and the small circle represents the *F*-star. The elliptical curve is the projected orbit of the *F*-star around the *I*-star. The abscissas are given in fractions of the semidiameter of the orbit, and the same unit has been used for the ordinate. A scale of the diagram is given in the lower left corner, which shows the size of one astronomical unit equal to the mean distance between the earth and the sun or one hundred and fifty million kilometers. The total length of the elliptical orbit in the sky equals 0.03 sec of arc. Accordingly, this diagram, if held at normal reading distance, corresponds to a magnification of roughly a half-million times.

its own axis with a speed of about 50 km/sec at its equator, when we observe the light of the *F*-star shining through the gas of the *I*-star, the rotation of the latter produces lines which are slightly displaced toward the red during the first half of the eclipse, and toward the violet during the second half of the eclipse.

These displacements, small as they are, can be measured. Great was the astronomers' consternation when they found that these displacements were not symmetrical; there was found a relatively small shift toward the red in the first half of the eclipse, and a much larger shift toward the violet after the middle of the eclipse. If the orbit were exactly circular, the shifts should be equal in amount. As a matter of fact, the orbit is not circular, but elliptical. When allowance was made for the ellipticity of 0.3 which was derived originally from the velocity curve in Fig. 4, the discordance in the Doppler displacement completely disappears. Thus the light provides still one more unexpected proof of our theory.

In conclusion, one may be interested in a few additional details. What about the distance of epsilon Aurigae from us? Its total luminosity is about 60,000 times that of our sun, and to our eyes it has a stellar magnitude of 3.3. The sun has a stellar magnitude of -26.7. Hence, the sun looks to us 30 magnitudes, or 10^{12} times brighter than epsilon Aurigae. Since, in reality, epsilon Aurigae is 6×10^4 times more luminous intrinsically, the ratio becomes 6×10^{16}. Now the intensity of light decreases as the square of the distance. Accordingly, the distance of epsilon Aurigae must exceed that of the sun, or 1.5×10^8 km, by a factor of $(6\times10^{16})^{\frac{1}{2}}=2.4\times10^8$. Accordingly, the distance of epsilon Aurigae is about 3.6×10^{16} km, and this is about 3000 light years!

This distance is large, but by no means unusual. We know many stars within the confines of our stellar system that are much farther away and, of course, many extragalactic nebulae are at distances of hundreds of millions of light years.

Nevertheless, the distance of epsilon Aurigae is sufficient to make us understand why we have not yet been able to observe the periodic oscillation of the *F*-component around the invisible *I*-star. The total amplitude of this oscillation would be only 0.03 sec of arc. On a direct photograph taken with the Yerkes 40-inch telescope, 10 sec of arc are represented by 1 mm on the photograph. The maximum oscillation of epsilon Aurigae every 13.5 yrs would, therefore, be equal to only 0.003 mm. This quantity is so small that we have not yet been able to measure it.

Lastly, the density of the invisible component of epsilon Aurigae is exceedingly small. Since its radius is 3000 times that of the sun, its volume is approximately 3×10^{10} times that of the sun. Hence, the mean density is 10^9 times less than the mean density of the sun. The latter is 1.42 in terms of water. Accordingly, the mean density of the *I*-star is about one million times less than that of air at atmospheric pressure.

The problem of epsilon Aurigae is solved (Fig. 5). We have discovered here a cool super-super-giant, a colossus even among stars, 3000 times the size of the sun,[7] surrounded by an ionized layer in its upper atmosphere. This layer owes its existence to the fortuitous proximity to a 6500-degree star of 60,000 times the sun's luminosity. Most important of all is the fact that, now we have knowledge of this unusual system, we may use this knowledge to guide our observations in the exploration of other regions of the sky, keeping in mind many details which may have been overlooked in the past.

[7] Only one other star of similar size is known. This is the red component of the binary VV Cephei, for which Dr. S. Gaposchkin of Harvard Observatory has recently announced a diameter of 2400 times that of the sun. The diameter of alpha Orionis (Betelgeuze) is approximately 400 times that of the sun.

Scientists, Historians, and the History of Science

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OF recent years there has been a rapidly developing interest in the study of the history of science in its relation to the process of social transformation in which it plays so great a part. The main initiative in such studies has come not from the historians, but rather from the scientists. This may have been due in part to the fact that many historians felt they lacked the necessary knowledge of science. A more important factor was probably the tradition of historical studies which interested historians in the *drama* rather than the *science* of history, and led them to study the role of human character and will in history rather than the play of sociological forces. Under the influence of this tradition most historians who have interested themselves in the history of science have been inclined to regard it as a history of great men who worked in seclusion, serving the ideal of knowledge for its own sake and without regard to the practical application of their work. Only very few have concerned themselves with the interaction of science and technology; fewer still have concerned themselves with the sociological studies in the history of science. Those who have, have done so in a way that shows a literary rather than a scientific approach.

The scientists, on the other hand, have turned to the history of science through the influence of events which have done much to undermine the faith they had in the value of their work. Since the rise of the modern scientific movement scientists have almost universally believed that their work necessarily contributed to the welfare of mankind, and that they therefore need not concern themselves with the ways in which their discoveries were actually put into practice. Now this faith is rudely shaken. They have recognized that the exploitation of science in the interest of private profit does not necessarily contribute to social well-being as a kind of by-product as was claimed. They have seen the results of scientific invention contribute to "overproduction" and unemployment; they have seen inventions suppressed and goods destroyed while the financial backing given to research whose results would be of social value has steadily decreased in proportion to that given to research directed at improving the engines of war. Furthermore, they have seen economic crisis leading on in many countries to Fascism and the suppression of all liberal culture, including the free pursuit of science itself.

This has led scientists to concern themselves with the study of the social processes which has led to such results. Their aim has been to discover what part science is actually playing in the process of social transformation and how the advantages of science can more effectively be brought to mankind. For this they had to turn to history. But in doing so they approached the study of the past with an attitude quite different from that characteristic of historians. They did not set out to interpret the past in dramatic form. Nor did they concern themselves especially with the role of personality in history. They sought to see history in its broad outlines and to discover principles which would provide an explanation of history as well as a means of prediction and control.

Many of the studies that resulted show all the faults of amateur work. These amateur historians have lacked historical erudition, they have not always been sufficiently critical of their authorities, they have not always reviewed the whole of the evidence and have often been hasty in arriving at conclusions. On the other hand, they have shown an ability to take a far wider view than most historians and have not let themselves forget the wood for the trees.

These two attitudes towards the history of science are well illustrated by two important books by Dr. S. N. Clark and Dr. B. Hessen.[1]

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[1] **Science and Social Welfare in the Age of Newton,** S. N. Clark (Oxford Press), 6/–.
"The Social and Economic Roots of Newton's Principia," in **Science at the Cross Roads,** B. Hessen (Kniga, London), 5/–.

Doctor Clark, in his book, makes a detailed study of the relations of science and technology to the social conditions of Newton's time. He weighs his evidence carefully, showing very great erudition and scholarship in doing so. He refrains, however, from suggesting any but the most tentative conclusions—except, perhaps, that no general conclusions are possible. Though his book is packed with the most interesting historical facts and references, he is extremely guarded about anything like sociological inferences. Doctor Hessen's essay, on the other hand, shows much greater boldness in drawing such inferences. He takes an attitude towards his problem rather like that of the biologist and regards social development as a process. He sees Newton's work as clearly influenced by the social conditions and the background of ideas of his time, and studies these in relation to the economic forces at work in the period. For him these forces, subject as they are to other social influences, such as those that arise from science, from technology, as well as from the structure of society itself, are of fundamental importance in shaping the historical process. In offering this entirely new conception of the history of science Doctor Hessen aroused immense interest when his paper was first presented to the International Congress for the History of Science in London in 1931.

The contrast between these two books is especially interesting not only because Doctor Clark's book shows clearly the influence of the approach made by Doctor Hessen seven years ago but also because an important part of his book is given up to a criticism of Doctor Hessen's work.

Doctor Clark is, of course, a very great authority on the history of the period and has given especial attention to its social aspects from the point of view of the historian. We can, without hesitation, accept his authority on all the particular issues on which he points out Doctor Hessen's errors. But though Doctor Hessen no doubt is in error over many of his facts, and though he may put far too great emphasis on the influence upon Newton of the ideas of the social class to which he belonged, his essay stands out as a brilliant synthesis, the broad outlines of which cannot be challenged and which removes historical processes from the realm of mystery.

The criticism that Doctor Clark brings to bear on Doctor Hessen's thesis is like that brought by so many historians against Mr. H. G. Wells' famous *Outline of History*. That, too, was open to many criticisms not only on grounds of historical detail but on the grounds of its general balance. Nevertheless, it did provide a very wide public with a book which, in spite of its defects, gave them a sense of history that was in its broad aspects true, and which had no rivals in anything that the academic historians offered. They, with their great preoccupation with strict accuracy on matters of historical fact, as well as with their suspicion of inductive generalization of the kind upon which science depends, would never have felt justified in writing such a book.

Doctor Clark goes very much further than most historians have done in studying the part played by science in the social process as it showed itself in Newton's time. He sees the scientific movement as influenced "from outside" by five major influences—economic life, war, medicine, the arts, and religion—and individual scientists working in universities as influenced from the "inside" by the traditions of pure knowledge as well. But for Doctor Clark the issues and relationships involved are too complex for anything much more general than this to be said. At the same time, he shows the influence of traditions of historical studies in that he is far too ready to accept states of mind as though they were ultimate historical determinants. Thus, we are constantly being disappointed by his analysis stopping short at such things as "administrative torpor," "conservatism," "instinct," "caution," "curiosity," "popularity," "the spirit of progress," and "lust for adventure" just at the point when we are most eager to know how these states of mind arose and upon what they depended.

It may be true enough to say that "The roots of social strife about inventions lie as deep as the belief in their value, for over against that belief there lies in the unreflective strata of our convictions a conservatism which makes us dislike them." Yet this is only a small part of the story. It is chiefly in putting emphasis upon such factors that Doctor Clark differs in his approach from Doctor Hessen who is prepared to speculate boldly as to possible causes. Doctor Clark will not accept anything that falls short of historical certainty. Doctor Hessen, on the other hand, through being willing to make guesses on a large number of individual points where certainty is impossible, builds up a picture of historical development which becomes steadily more impressive. Though in the process he may fall into a number of historical errors which make him easy prey for the historians, it does not destroy the picture he presents, or the value of his method as it may be used to approach other periods of history. In view of all this, Doctor Clark's criticisms remind one rather of the criticisms brought against the theory of evolution on the ground of the inadequacy of Darwin's principle of natural selection.

Doctor Clark's book is of great value in correcting the numerous mistakes in Doctor Hessen's essay and in providing a great deal of material, and clues to further material, that should be of the utmost value to other scientists who make further studies along the lines opened up by Doctor Hessen's essay.

The beginning of wisdom is found in doubting; by doubting we come to the question, and by seeking we may come upon the truth.—PIERRE ABELARD.

A Study in Laboratory Manuals

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IN 1934 the University of Oregon, with the assistance of a grant from the Carnegie Foundation, undertook the study of the various factors that enter into present laboratory practices. One project was to study the laboratory manuals now used in the American colleges and universities, with the thought that some light might be thrown upon the problem as a whole. With this in mind, we sent out a questionnaire requesting information regarding the different manuals used. Sixty-three different manuals used in colleges, universities, and technical schools were received either from the authors or publishers, or were obtained by purchase.

Each manual was carefully studied, and all experiments were listed and given a serial number to designate the source. If the experiment covered more than one subject, additional listings were made. On the other hand, if a subject extended over more than one experiment (separately numbered by some authors), only one serial number was used. However, we believe the use of subjects as the basis of study was better for the problem in hand.

The 3343 experiments included in this study were classified into the six divisions listed in Table I. It will be seen that mechanics and electricity constituted 56.6 percent of the total work in the average laboratory course of college physics, with the other four divisions covering only 43.4 percent of the work.

Because several of the manuals submitted were rather specialized, we selected fifty-three of the normal type and made a detailed study of the percentages of experiments in each. In this study measurement was included with mechanics, but otherwise the usual procedure was followed. We found that the average percentages for these manuals varied little from that for all manuals, and that the variations within each group were still quite wide. Mechanics varied from 20.8 to 47.0 percent of the total work covered in a manual; heat, from 6.9 to 28.4 percent, with one manual zero; sound, from 2.0 to 10.8 percent, with two manuals zero; electricity and magnetism, from 11.6 to 43.1 percent, with one manual zero; light, from 8.0 to 27.0 percent. The variations indicate the nonuniformity of the first-year laboratory course. The average number of experiments in the selected group of manuals was 60.9. In our work we used sixty as the average number of experiments.

The six main divisions were divided into subject titles that most closely fitted the nature of the experiment (Tables II–VII). Some criticism can be made of our selection of subtitles and the distribution of various experiments under them in individual cases, but the titles used were those that conformed most nearly with general practice as found in the manuals. An illustration of this is in mechanics, where we have used the subdivisions *simple machines*, *torques*, and *moments*, under any of which the experiment on the lever might be classified. The intent of the

TABLE I. *Number of experiments in each division.*

DIVISION	NO. OF EXPS.	PERCENT
Measurement	162	4.8
Mechanics	945	28.3
Heat	465	13.9
Sound	208	6.2
Electricity	946	28.3
Light	617	18.5
Total	3343	100

TABLE II. *Summary for measurements.*

SUBJECT		No.
Length (area and volume)		141
General	24	
Comparison of units	13	
Vernier caliper	30	
Micrometer caliper	22	
Spherometer	22	
Calibration	8	
Angular units	7	
General	15	
Length, mass, and time (combination)		6
Miscellaneous measurements		15
Slide rule	2	
Levels	3	
Mathematics (use)	6	
Manometer	1	
Graphs (curve plotting)	3	
Total		162

TABLE III. *Summary for mechanics.*

SUBJECT		No.	SUBJECT	No.
Hydrostatics		113	Surface tension	34
Boyle's law	41		Moment of inertia	33
General	72		Determination of g by falling body	23
Simple machines, efficiency		100	Force	18
Analytic balance	27		Center of gravity	17
Lever	10		Projectiles	17
Pulleys	18		Weight and mass	14
Inclined plane	20		Efficiency	11
General	25		Momentum	11
Density		95	Viscosity	10
Elasticity		83	Centrifugal force	12
Torques		74	Work and power	8
Vectors and scalars		68	Acceleration, linear and angular	7
Simple harmonic motion		63	General	14
Determination of g by pendulum		43	Total	945
Friction, coefficients of		40		
Specific gravity		37		

experiment was followed as nearly as possible; that is, if the lever was used to teach the principle of torque, it was so classified, whereas if it only demonstrated the lever as a machine, it was placed under simple machines.[1]

Although the average manual endeavors to emphasize the basic principle of physical measurements (Table II), there is a tendency in a number of manuals to use such specialized equipment as the planimeter, cathetometer, and the dividing machine. Most of the experiments emphasize linear and angular measurements that should prove of considerable value to the student. In several manuals, emphasis was placed on the determination of mass as an experiment in measurement rather than as a dynamical experiment. A number of the experiments in measurement appear to be too elementary for the college level.

Table III shows that seven experiments dominate mechanics; these are in hydrostatics; simple machines, such as the balance and inclined plane; density; determination of elasticity; torques; vectors and scalars; and simple harmonic motion. It must be pointed out, however, that such essential concepts as force, acceleration, inertia, work, and momentum, are in the minority, while an experiment dealing with energy directly is given in only one manual. It is true that the experiments mentioned do deal with these concepts indirectly, but it is the opinion of the author that they fail to place sufficient emphasis on the fundamental principles that should drive home the meaning of, rather than something about, physics. In Table IV we find that specific heat is in the lead. In general, the experiments cover the field as given in the average text, but such essential concepts as Joule's equivalent, evaporation, and conduction of heat, are neglected. In many manuals these items are omitted altogether. In others they are partially covered in general experiments or as a subdivision of another main topic.

In Table V we find the determination of the speed of sound by various methods heading the list with 70 experiments. The study of sonorous bodies and the determination of pitch constitute the usual experiments in the average manual. The study of acoustics is omitted from practically all manuals, an extremely bad practice, as one of the greatest developments occurring today is in this field. When the subject of sound is mentioned, usually the first thought that occurs to us is music or speech. Yet the number of experi-

TABLE IV. *Summary for heat.*

SUBJECT		No.	SUBJECT	No.
Specific heat		76	Hygrometry (humidity and dew point)	26
Gases	1		Joule's equivalent	23
Solids	40		Evaporation and vapor pressure	17
Liquids	28		Conduction of heat	16
General	7		Heat of combustion	15
Thermometers		51	Radiation	13
Heat of fusion		47	Pressure-temperature curves	12
Linear expansion		47	General	22
Changes of state		35		
Melting point	16			
Boiling point	13			
General	6			
Heat of vaporization		33		
Volume expansion		32		
Gases	16			
Liquids	12			
Solids	4		Total	465

TABLE V. *Summary for sound.*

SUBJECT		No.
Speed of sound		70
Resonance tube	20	
Kundt's tube	19	
General	31	
Sonorous bodies		47
Air columns	5	
Strings	35	
General	7	
Pitch and frequency		33
Waves (longitudinal, transverse and general)		26
Wave-lengths		11
Resonance		9
Interference and beats		7
Musical sounds		2
General		3
Total		208

[1] The original work sheets, as well as complete lists of the manuals studied and the institutions where they are used, are available to anyone who cares to study them.

ments directly on these topics is extremely small, there being one directly on overtones, one on scales, seven on beats, and none directly on the voice or hearing.

In Table VI, on electricity and magnetism, the experiments were classified in the particular way shown because of the fact that many of the experiments in the manuals involved duplications of one basic principle rather than the introduction into a new field. This is especially true in electrokinetics where we find 33 experiments on Ohm's law directly, 82 on electromotive force, and 191 on resistance. Basically, these three subdivisions all endeavor to correlate the three factors of Ohm's law. While a certain amount of duplication is necessary, it often proves wasteful of the student's time to arrive at the same conclusions by almost similar methods, thus preventing his study of other important fields. The omissions in electricity and magnetism lie largely in the experiments that deal with more modern concepts and methods, such as the electron, photoelectricity, thermoelectricity, and vacuum tubes.

TABLE VI. *Summary for electricity.*

SUBJECT		No.
Electrokinetics		355
Ohm's law	33	
Electromotive force	82	
Resistance	191	
Circuit studies	49	
Magnetism		168
Nature of magnetism	9	
Magnets	2	
Magnetic fields	61	
Field strength	67	
Magnetic dip	9	
Hysteresis	10	
Magnetic permeability	3	
Coulomb's law	7	
Electromagnetic induction		113
Electromotive force	28	
Lenz's law	2	
Mutual and self-induction	33	
Transformers (including induction coils)	8	
Dynamo	13	
Analysis of motors	22	
General	7	
Instruments		99
Chemical effects		43
Voltaic cells		36
Electrostatics		31
Capacitance		30
Heating effects		29
Electrical devices		16
Thermoelectricity		17
Vacuum tubes		8
Electromagnetic waves		1
Total		946

TABLE VII. *Summary for light.*

SUBJECT		No.
Optical instruments		110
Microscopes	44	
Telescopes	46	
General	20	
Reflection		103
Images	92	
General	11	
Refraction		100
Index	89	
General	11	
Lens		83
Dispersion		74
Photometry		57
Wave-length of light		29
Interference		25
Polarization		18
Defects in mirrors and lenses		11
General		7
Total		617

In light (Table VII) the emphasis is on reflection; refraction; lenses; optical instruments, such as microscopes and telescopes; and dispersion; with photometry following closely. Experiments on interference and polarization were in the minority.

Taking the average number of experiments per manual as 60 and the percentage averages given in Table I, we found that the average college manual has approximately 3 experiments in measurements, 17 in mechanics, 8 in heat, 4 in sound, 17 in electricity and magnetism, and 11 in light. Our "average manual" would then contain the number of experiments from each of these groups beginning with those that occur most frequently. In many manuals the experiments on the same topic were repeated, in whole or part; however, to determine the actual contents of our average manual, this must be considered. In Table VIII we have given the actual fractional part of experiments which would be in the average manual as found in this study. In order to arrive at an ideal manual, the author has adjusted the fractional differences and included certain other basic experiments which, in the light of this study, seem to need greater emphasis in order to teach basic principles properly. This is given in the third column of Table VIII. The ideal manual classification is slightly different as often one experiment may cover more than one

TABLE VIII. *Contents of the average and ideal manuals.*

EXPERIMENT	AVERAGE NO.	NO. IN IDEAL MANUAL
Measurement		
Angular measurement		1
General, including use of slide rule, plotting graphs		1
Length, area, volume	2.60	
Linear measurements		1
Miscellaneous	0.40	
	3.00	3
Mechanics		
Determination of g	1.22	1
Density and specific gravity (one each on liquids and solids)	2.20	2
Elasticity	1.38	1
Energy, work		1
Force (Newton's 2nd law)		1
Friction	0.67	
Hydrostatics	1.88	2
Mass and weight		1
Moment of inertia	0.55	1
Momentum		1
Simple harmonic motion	1.05	1
Simple machines, efficiency	1.67	1
Surface tension	0.57	1
Torques, moments	1.23	1
Vectors and scalars	1.13	1
Viscosity		1
Miscellaneous	3.45	
	17.0	17
Heat		
Changes of state	0.58	1
Conduction, convection and radiation		1
Volume expansion	0.53	
Evaporation and vapor pressure		1
Heat of fusion	0.78	
Heat of vaporization	0.55	
Hygrometry	0.43	1
Linear expansion	0.78	1
Joule's equivalent	0.38	1
Specific heat	1.27	1
Thermometers	0.85	1
Miscellaneous	1.85	
	8.00	8
Sound		
Acoustics		1
Musical instruments		1
Pitch and frequency	0.55	1
Sonorous bodies	0.78	
Speed	1.17	1
Waves	0.43	
Miscellaneous	1.07	
	4.00	4
Electricity		
Capacitance	0.50	1
Chemical effects	0.72	1
Electrical instruments	1.65	1
Electrokinetics	5.95	4
Ohm's law		(3)
Circuit theory		(1)
Electromagnetic induction	1.88	3
Induction		(1)
Dynamo analysis		(1)
Motor analysis		(1)
Electrostatics	0.52	1
Heating effects	0.48	
Magnetism	2.95	2
General		(1)
Magnetic fields		(1)
Photoelectricity		1
Electrons		1
Thermoelectricity		1
Vacuum tubes		1
Voltaic cells	0.60	
Miscellaneous	1.75	
	17.0	17
Light		
Dispersion	1.24	1
Interference	0.42	1
Lenses	1.38	1
Optical instruments	1.83	2
Photometry	0.95	1
Polarization	0.30	1
Reflection	1.72	2
Refraction	1.67	1
Spectroscopy (wave-length)	0.48	1
Miscellaneous	1.01	
	11.0	11
Total experiments	60.0	60

subject if the association is close. Naturally, the method of writing the experiments will help to determine the success of any manual, but we think that a manual should cover the basic principles of physics if it is to be of real assistance in the regular college course.

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The Problem of Choosing a Textbook—An Approximate Solution

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IF it was true two thousand years ago that "of making many books there is no end, and much study is a weariness of the flesh," and if we now add the choosing of a textbook as an additional form of "study," we must feel that the great increase in the output of books in recent times is not wholly a blessing. Every experienced teacher knows the worry and weariness that accompany prolonged comparison of a number of textbooks before reaching a decision; but, as in the case of the weather, while we talk a lot about it, no one seems to do much about it. If I now venture to offer something like a preventive of this form of worry, I hope it will be regarded as merely a first rough approximation to a solution, one that may, if it has any merits at all, be improved by others. With so many good books available in increasing number, the need for a solution, however imperfect, becomes more and more urgent.

Before considering the proposed solution, let us glance briefly at the nature of the problem. When a book—call it B—has ceased to be satisfactory to a teacher, he must find another —say B'—that is on the whole superior to B as regards *his* requirements. But how is he to find time, energy and patience to compare two or more books closely as regards *all* relevant qualities? And, even if he goes through with it, how is he to decide which book is *on the whole* the best for his purposes? These and other difficulties lead to some kind of simplification of the process. Attention may be confined, more or less consciously, to a few outstanding requirements. Naturally, particular attention will be given to topics on which B was unsatisfactory. Parts that met approval in B may not be scanned at all closely in B'; they may even be taken for granted, with unfortunate results. When, as sometimes happens, the distasteful work is unduly postponed, perhaps because it is rather irregular kind of work, until a quick decision becomes necessary, the result may depend on the mood of the moment. Other influences may intervene, such as opinions on the book B expressed by students. These are sometimes useful and sometimes misleading, so that they have to be treated with caution. Two or three years ago some students in a large class were of the opinion that their textbook B was not satisfactory. So next year B was replaced by B', and then it was found, after a few weeks, that many students were getting their work up at home from old copies of B. I suppose the only moral to be drawn from such incidents is that a dependable method for choosing a textbook is desirable —if it is possible.

Coming now to the approximate solution that I am venturing to offer, I may summarize it at the outset by saying that it consists essentially of *setting an examination for the competing books* and then marking them on the results, all pretty much in the ordinary way, except that the same examination paper could be used year after year (and cribbing would be impossible).

I start with the assumption that any experienced teacher can make a list of the desirable qualities or "requirements" of a satisfactory book, each requirement being practically independent of the others. Any such list is, of course, the particular teacher's own list, not something objective and acceptable to others. This is just as it should be, for any rational decision must be the work of an individual, either as to the book he will choose if the choice rests entirely with him, or as to his vote in a group that is responsible for the choice. My own list for the purpose consists of ten requirements. I could give it here, but I think it better not to do so; I would be likely to prejudice the reader in drawing up his own list, and the discussion of my list might distract attention from what I still have to say. So I ask the reader to draw up his own list. He should not put into it any absolute rules that he must apply, such as "no calculus," for they are not used in comparing books about which he is still in doubt.

The second step is to arrange these requirements in their order of importance. This is not at all a difficult thing to do. If I say that a

weakness in some requirement X would be more detrimental to the work or give me more trouble in teaching than a weakness in some other requirement Y, I am rating X higher in importance than Y. Here again teachers will differ, and this is also just as it should be, if everyone is to act rationally according to his own judgment. If anyone should find that the requirements, as he has formulated them, are, to his mind, of about equal importance, he is in luck and need not do any arranging. But he should take care to be as clear as possible about the matter.

The third step is to "weight" these requirements numerically in accordance with what you regard as their importance (if you do not think them equally important). As the weighting will be only a rough estimate, it will be useless and illusory to employ too fine a scale. So I would suggest that the most important be given a weight of 10. In doing this weighting, teachers will again differ in their judgments, and this is also just as it should be. It may be objected, however, that these numbers are too uncertain to be relied on. Yet you do give some kind of ratings of importance to different requirements, when you are comparing two books without using numbers, and the numbers are as useful and justifiable for expressing your judgment as vague general terms like "important," "very important," and so on. So you cannot be doing anything illogical or prejudicing the decision in any way, if, *in order to be able to integrate your judgments*, you use figures as accurately as your judgment will permit.

It may be noted that this process of listing the different requirements and then comparing them carefully as to their importance is excellent exercise in the relative importance of things in teaching, and it may possibly help anyone who does it to revise earlier and less mature ideas.

The final step is now obvious. Write your list of requirements in a column; and, in a second column, enter the weights you have assigned to them. Then in other columns, headed A, B, C, . . . for the books to be compared, put the "marks" you give to the books as regards the different requirements, each mark being on the basis of the weight of the requirement as a perfect mark. For example, if the weight is 8, each book is marked 8 or 7 or 6 . . ., according to your judgment of how far it satisfies that requirement. This kind of grading can be done with approximately the precision possible in marking many questions in an ordinary examination, and it is certainly as dependable and significant as the use of adjectives like "good," "very good," or "poor" in the ordinary method of comparing books.

All that is now necessary to get the final grade on each book is to add up the A, B, C . . . columns, and your problem is solved, unless you think it desirable to revise parts of the work.

A decision arrived at in this way seems much more dependable and satisfying, since it is the result of an all-round survey of things in something like their proper proportions, a method that might be called *balanced circum-spection*, for lack of a better term.

Since the method proposed is much more definite and systematic than the ordinary method, the work can be pushed more rapidly and a trustworthy decision can be reached in a shorter time and with less worry, for indefiniteness in working begets uneasiness and worry. The method also has the advantage that, if the work is interrupted at any stage, there is a definite record of what has been accomplished, and the work can be resumed at any time without confusion or repetition.

In fact, the two methods differ in about the same ways as the two possible methods of grading a lot of examination books; the first method being the familiar one in which each question is marked separately and the marks are added to get the grade, while the second method would dispense with any detailed marks, and the examiner, after reading all that a student has written, would have to depend on some vague estimate for a grade. There can be no doubt as to which method is more reliable, whether students or books are being examined.

It should, perhaps, be repeated that, in making a group choice, each should work out his own result and then vote accordingly. It may be possible to agree on the list of requirements—perhaps after an instructive discussion—but the weighting had better be left to the individuals (if the requirements are not thought to be of

equal importance). The work can be lightened by assigning a certain number of the requirements to each individual, but the final result would then be much less reliable.

There is, of course, no promise of certainty of results by this, or any other, method. Certainty as to the future is beyond man's wisdom; all he can rely on is probability, and it should be weighed as scientifically as possible.

If this general method which I have called balanced circum-spection should commend itself to others, it ought to be applicable to textbooks on all subjects and perhaps also, with suitable modifications, to difficult decisions in other fields. I have, myself, found it very useful and a great saver of time and worry on occasions when I could not "make up my mind" by the ordinary method of somewhat random rumination.

Student Opinion of Laboratory Experiments

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WHEN the topic of student opinion on matters of instruction is introduced into a discussion the question immediately arises—"What weight shall we give to student opinion?" Experienced teachers have developed and are developing certain laboratory experiments for first year college physics which they feel are important in conveying to the students impressions and appreciations of the fundamental features of the course. Certainly the students do not have the experience and background necessary to know what the subject holds of value to them. They are, therefore, in no position to select a better group.

The selection of the material for presentation, is, however, not the end. One of the first facts that impresses itself on the beginning teacher is the importance of presenting this material in a manner which will gain the interest and support of the student. Here we may profitably make use of student opinion without upsetting the apple cart. For example, does the accuracy of the result obtained in the performance of an experiment help in producing the impression we desire?

In an attempt to get such information from the students concerned, we have, during the past several years, distributed the questionary in Table I at the end of the last laboratory period of the semester. Approximately 70 percent of the students, in classes under eight different laboratory instructors, took the time and trouble to fill out and return the sheet. It was decided to sacrifice a more complete return in order to obtain the greater reliability resulting from complete anonymity.

We shall be concerned primarily with the information gathered under the headings, "Remarks," "Why?," and the suggested general changes. These statements were analyzed and classified as accurately as possible. A composite picture of some 400 replies is given in Tables II and III.

TABLE I. *Questionary.*

We are interested in knowing which of the following experiments have been of value to you in the physics course this semester, and which ones you think are weak and should be improved or dropped. This will help us determine the changes to be made to benefit the students next year. Please give your candid opinion and feel perfectly free to make any remarks you think the particular experiment deserves. Do not sign your name.

EXP. NO.	NAME OF EXPERIMENT	GOOD	FAIR	POOR	REMARKS
50	Magnetic field and pole strengths				
55	Comparison of condenser capacitances				
60	Fundamental experiments in electricity				
65	Mechanical equivalent of heat				
62	Wheatstone bridge				
68	Trouble finding in electric circuits				
64	Electrochemical equivalent of copper				
63	Comparison of electromotive forces				
66	Electron tube characteristics				
79	Photometry				
81	Concave mirror				
80	Refraction of light				
82	Study of lenses				
84	Wave-length of light				

Which two experiments do you consider the best? Why?
Which two experiments do you consider the poorest? Why?
What general change should be made in this laboratory work to improve it for the next class?

TABLE II. *Summary of reasons why certain experiments were chosen as best.**

	PERCENT
1. Clarified difficult (or vague) topics	15
2. Showed interrelation of fundamental laws	6
3. Illustrated (or impressed) fundamental ideas	17
4. Introduced entirely new ideas	5
5. Practical application apparent	30
6. Gave accurate (or convincing) results	8
7. Methods clear (or concise)	14
8. Fine apparatus	5

* Reasons not classified: "interesting," "sensible," "fascinating," etc.

TABLE III. *Summary of reasons why certain experiments were chosen as poorest.**

	PERCENT
1. Laboratory experience not needed	
Material known and accepted	20
Could be done outside of laboratory	11**
Did not involve fundamentals	8
2. Results inaccurate (or unconvincing)	13
3. Poor apparatus	9
4. Method too involved (or mathematical)	13
5. Could not understand—vague instructions (or theory)	19
6. No practical application apparent	7

* Remarks not classified: "dry," "uninteresting," "did not fit," etc.
** 80 percent of these remarks concerned one particular experiment.

In Table II, 43 percent of the replies gave subject matter (the first four items) as the basis of selection of the best experiments of the semester. Another 30 percent were based on the grounds of apparent practical value. At least 8 percent indicated that accuracy of the results was the convincing factor, and the remainder based their selection on method and apparatus.

In Table III the first item, totaling 39 percent, should be discredited since the 11-percent subitem was too heavily weighted. It, however, shows a desirable reaction of the student to his laboratory work; he is interested in adding to his knowledge of the subject rather than repeating the easier, familiar material. Thirteen percent of the replies rated an experiment as "poorest" because of inaccurate results; apparently many students are not satisfied unless they can come within a few percent of the accepted values. Items 4 and 5 are a challenge to the laboratory instructor.

Many of the replies to the last question of the questionary are of interest. A few, representing those most repeated, follow:

The system of partners should be discontinued as it tends to encourage the laziness of some and throws a greater burden on others.

Double the time spent in the laboratory and have the student construct more of his own apparatus; then he is forced to think through the experiment in order to correctly put together an apparatus for performing it.

The instructor should explain "not accepted" reports more fully.

There should be a class discussion for the first 10 or 15 min of each laboratory period; this should be a summary of the material to be covered and an explanation of particular points to be noted.

Studying before coming to the laboratory should be made compulsory; this would increase the value of the laboratory time.

Make sure the student knows the objective of the experiment.

In general those experiments are best that aim most directly at their purpose rather than leading through a maze of figures and formulas.

In the poorest experiments the computations are complicated, and hence the results reached are obscure and doubtful.

A very short but comprehensive review of the mathematics used in the course should be given at the beginning.

It was fascinating to see how well some of the experiments yielded acceptable values.

In some cases more accurate instruments would help in obtaining better results and thus heighten the interest in the work.

The concepts involved in these experiments are made many times more understandable by the use of the apparatus than by reading or listening to lectures.

The value of the laboratory work, as I see it, is to derive additional information about a subject that is obscure from book discussion and lecture alone.

It gives the experimenter a great deal of satisfaction to see his problem work out right before him.

I liked these two experiments because they showed, in a way that was clear to me, that these phenomena did exist.

The indicated wants expressed by the students in this questionary are a distinct challenge to the instructor in the first year physics laboratory. New, fundamental, useful ideas presented by simple, understandable methods which give convincingly accurate results, appear to impress the majority of the students with the desirability of mastering the subject. The results of the efforts of the teacher will be considerably determined by the extent to which he can successfully meet such expressions of student opinion.

A Feasible Modification of the Dewey Physics Classification

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IN a recent article,[1] Miss Shields has pointed out the necessity for a logical scheme of classifying books in physics, and has proposed a rather radical modification of the present Dewey decimal system. About two years ago, this writer, in collaboration with Professor F. W. Loomis and with Mr. A. H. Trotier, the University catalog librarian, reclassified the books in our library according to a scheme which involved much less change in the Dewey system, and which adhered as closely as possible to the theory of that system. Since the cataloging now proceeds very smoothly and correctly, with practically no advice from the physics department, it seems of interest to present here the scheme which was adopted.

An underlying idea of the Dewey system demands that works of a general nature in a subject precede those of a specific nature. In addition, the subdivision *.1* is reserved for the theory of the subject. Thus, general works on optics are to be classified under *535*, and books on the theory of light under *535.1*. The subdivision *.8* is usually reserved for applications.

Our really major change (Table I) was the adoption of the number *539* for books on atomic physics, the word "atomic" being construed in a broad sense. Theoretical works on atomic physics then come under *539.1*, with subdivisions *539.11* for electron theory and *539.12* for kinetic theory and statistical mechanics (these two subjects being so closely related that there should not be two separate numbers for them). Since radioactivity is a property of the atomic nucleus, it seemed natural to put radioactivity and nuclear structure under one heading. In general, the classification should not be too fine.

The number *530.1* had been used for almost anything of a general nature, so that books having little connection with each other were side by side. It was decided to reserve this number for the philosophy of physics, and to create an arbitrary number *530.02* for the numerous texts on theoretical and mathematical physics. The number *530.01* is now used for all the elementary textbooks.

There was some question as to where the books on relativity should be placed, since the subject is related to mechanics and to electrodynamics.

TABLE I. *Illinois modifications of the Dewey system.*

530.01	Textbooks and laboratory manuals (elementary).
530.02	Theoretical general physics; mathematical physics.
530.03	Special properties of matter; properties of solids; elasticity, etc.
530.1	Philosophy and logic of physics.
531.51	Relativity, general and special.
533.7	(Kinetic theory, changed to *539.12*).
533.85	Vacuum technic.
535.3	Geometrical optics; reflection; refraction.
535.4	Dispersion; scattering; absorption; emission.
535.5	Wave optics; interference; diffraction; polarization; double refraction; crystal optics.
535.84	Spectroscopes and spectrum analysis (see *539.41* and *539.42* for interpretation of spectroscopic results).
537.1	Electricity, theory and nature; electrodynamics; electromagnetic theory.
537.26	Dielectric constants; electric moments.
538.4	Diamagnetism, paramagnetism, and ferromagnetism; magnetic moments; magnetic susceptibility and permeability.
539	Atomic physics; subatomic phenomena (general); electrons, protons, positrons, neutrons, etc.; electron optics; electron diffraction; molecular and atomic beams.
539.1	Theory; quantum theory; wave mechanics; matrix mechanics; group theory and other special methods in their application to quantum theory.
539.11	Electron theory; electron theory of matter; electron theory of metals.
539.12	Kinetic theory and statistical mechanics.
539.2	Electric discharge through gases; ionization; collision processes; cathode rays; positive rays; canal rays.
539.21	Thermionics; vacuum tubes.
539.22	Photoelectricity; photoelectric cells.
539.3	X-rays; Compton effect.
539.4	Atomic and molecular structure.
539.41	Atomic structure and line spectra. } See also
539.42	Molecular structure and band spectra. } *535.84*
539.5	Radioactivity and nuclear structure; mass spectra; isotopes.
539.6	Cosmic rays.

[1] M. C. Shields, Am. Phys. Teacher **6**, 8 (1938).

Because general relativity is concerned with gravitation, it was finally decided to put these books together, and to adopt the number *531.51* for all books on relativity.

After putting all books on electrodynamics and electromagnetic theory into *537.1* and making minor changes in the subdivisions of *535*, the only other question left was how to dispose of a few books on special properties of matter (solids in particular). The arbitrary classification *530.03* was adopted, principally because there seemed to be no logical place for such books. A radical alternative would be to combine *532* and *533* under the heading "fluids" and to adopt *533* as the heading for solids. This was not done because it would involve the reclassification of more books, although it is probably desirable.

The net result of all this was that the divisions *531–538* were left pretty much intact, so that the expense of the change was held to a minimum. Our modifications have been made mainly with the idea of having an up-to-date workable system, and we believe that we now have one. It has not been necessary to reclassify many of the older books, since the official Dewey system took care of them fairly well.

What is the Meter-Kilogram-Second System of Units?

A Report of the A.A.P.T. Committee on Electric and Magnetic Units

SCARCELY more than a half-century ago advocates of the c.g.s. system of units assumed an apologetic attitude. An immediate justification of their position was necessary. Today, when we advocate a more extended use of a meter-kilogram-second system of units, a few preliminary words of explanation may likewise be necessary. As physics teachers we have been partners, either active or passive, in the development of a wide diversity of units, especially in the field of electricity and magnetism. It is necessary now to take some cognizance of present trends, and recognize the action of other international bodies.

Two recent decisions are of particular interest. The International Committee on Weights and Measures has decided to discard the international ampere, ohm, volt, etc., in favor of those units based on so-called absolute measurements. This is to take effect January 1, 1940. The change involved in actual measurements is very slight, and is of importance only in the most precise work. Our textbooks, however, should be revised in those places where electrical standards are discussed. Various national standardizing laboratories are at work on measurements leading to the more accurate establishment of these units. It is believed that the ohm and ampere can now be reproduced more accurately by these measurements than is possible by means of the present legal standards.

The second action, which is of greater interest to us now, is the adoption by the International Electrotechnical Commission of a meter-kilogram-second system of units. This system is to include the electrical units in common use—the ampere, volt, ohm, coulomb, henry, and farad, as well as the joule and watt. This action, so far as it goes, is in accord with recommendations made in a previous report of this committee.[1] It is by no means new, but it may not be generally recognized that the common electrical units named above fit into a coherent system based on the three mechanical units—the meter, the kilogram, and the second. There are, however, a number of ways of completing the system to include other units such as those for electric and magnetic fields. The big problem before us is the choice of these other units and the definitions involved.

In building up such a set of units, there are many questions that cannot be satisfactorily answered without a great deal of time and discussion. Even then some differences of opinion

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[1] Am. Phys. Teacher **3**, 90 (1935).

are almost certain to remain. The attempt has been made to have this report set forth the consensus of opinion of the whole committee, but each individual would desire some changes or some shift in emphasis. The fact that there is not yet complete agreement seems of minor importance in comparison with the need of presenting this work to all physics teachers for their careful consideration. The chairman assumes the responsibility for any false or misleading statements.

The adoption of an m.k.s. system by any committee does not mean that it will be immediately accepted and put into use by all physicists and engineers. It must stand on its own merits. To receive any general adoption, however, it should be widely publicized, and its advantages, as well as its limitations, made known. There is no hope that any one system of units will completely supplant all other units; but it is hoped that a great simplification will be brought about by the gradual abandonment of a number of units and incomplete systems.

There has been a considerable divergence of opinion between theoretical physicists and electrical engineers. Part of this, doubtless, is due to real differences in the needs of the two groups, but the major difficulty seems to result from a lack of understanding of each other's problems and points of view. To meet the needs of both groups, our committee recommends that two systems be used—the m.k.s. system and the Gaussian or the Heaviside-Lorentz system. One of the latter systems would be used where desired for theoretical work, but it would not need to be taught to the beginning student.

There should be closer cooperation and better understanding between engineers and physicists. Engineers are usually taught their first electricity by physics teachers. Of the vast number of different units used by engineers, the majority have been introduced by physicists, or first taught to the beginning engineers by physics teachers. Engineers apply physical principles and make measurements. They make and calibrate instruments, and these same instruments are used by physicists. Therefore, it would seem to be the duty of physics teachers to put their own house in order and to teach a coherent system that serves the purpose of the engineers. It is peculiarly fortunate that the electrical units most widely used by both physicists and engineers—the volt, ampere, watt, etc.—fit so nicely into a complete m.k.s. system.

It is hardly necessary to stress the difficulties and confusion arising from our present multiplicity of systems. There are in use the Gaussian system, the Heaviside-Lorentz system, an electrostatic system with three dimensions and one with four, an electromagnetic system with three dimensions and one with four, the legal or international system, and the practical system. In general, no one of these systems is used to cover the whole field of electricity both in theoretical and practical work. And perhaps nowhere can one find a complete list of defining equations and definitions for all the common electrical quantities and units in these various systems. The usual elementary text starts with an electromagnetic system for magnetism, shifts to an electrostatic system for electrostatics, back to an electromagnetic system for the fields produced by currents, then either to the practical or the international system for Ohm's law, and from then on it is usually a hopeless mixture. Each system may be started very logically but it is not completed.

It is true that each of these systems has its special advantages for the field in which it is usually applied. For example, it is easier to compute the capacitance of a condenser in electrostatic units than in farads; but aside from getting the answer to a formal problem, how often does one desire the capacitance in electrostatic units? Laboratory measurements are usually made in volts, amperes, farads, etc. Again, it is a distinct inconvenience that in the m.k.s. system ϵ_0 and μ_0 are not each equal to unity. The values for these two constants need to be remembered and used in any equation where ϵ or μ appear. This, however, is considerably simpler than remembering all the conversion factors for the units in the several systems. It will also be noted that the size of the m.k.s. units is inappropriate for certain fields. The coulomb and the farad are very large units for electrostatics. It is useful here to use the prefixes *micro* (μ) and *millimicro* ($m\mu$); thus microfarad, millimicro-coulomb, etc., as was suggested in an earlier report.[1]

The question arises as to whether, in the field of mechanics, the c.g.s. system should be replaced by the m.k.s. system. It is likely that this change will take place, but the change is much less than might at first be suspected. Names for most of the units are already in common use. The important exception is the *newton* as the unit of force. This name has been used here because it seemed suitable and appropriate, and also because it has already appeared in a text.[2] The newton is a unit of reasonable size, being approximately 102 grams of force. The kilogram, meter, joule, and watt are at present used almost as much as the gram, centimeter, erg, and erg per second. It is also comparatively easy to remember g as 9.8 m/sec.[2]

The list of definitions which follows is not intended to be complete or final, but it may serve as a common basis for argument. It will be noticed that we have chosen a so-called "rationalized" system. The term *rationalization* is here used in a very special sense, and refers only to the location of 4π in certain equations. For example, magnetomotive force is expressed in *ampere-turns* rather than 4π *ampere-turns*. This question and some others are discussed more fully following the definitions. It is impossible, however, to consider in detail in this report more than a small fraction of the questions that have arisen during the committee's deliberations.

Definitions of Terms and Units

Electric current. The presence of an electric current in a conductor may be ascertained by various effects, such as heating, electrolytic action, magnetic effects, etc. For purposes of measurement, we choose a method depending upon the forces acting between conductors carrying currents.

The *ampere* is then defined as being that unvarying current which, if present in each of two parallel wires of infinite length and 1 m apart in a vacuum, will cause each wire to experience a force of 2×10^{-7} newton (0.02 dyne) for each meter of length of wire. The name *newton* is here used for the m.k.s. unit of force, or 1j/m. The ampere thus defined is the ampere of the practical system; that is, 1/10 of the c.g.s. electromagnetic unit. The ampere, consistent with this definition, can be established quite accurately by means of the current balance.

This definition involves no assumption regarding the variation of the force with the currents and the distance apart of the wires; but, to be consistent with what follows, the relation will be $F=\mu i_1 i_2 l/2\pi r$ in the rationalized m.k.s. system. In this system, μ_0 is $4\pi\times10^{-7}$ newton/amp.[2]

Electricity (*quantity of electricity*, or *charge*). The product of the current in a conductor and the time gives the electricity passing a cross section of the conductor in that time; $q=\int idt$.

The *coulomb* is that quantity of electricity which, in one second, passes through a cross section of a conductor in which there is a constant current of 1 amp.

Potential difference. The difference of potential between two points A and B is the quotient obtained when the work done in moving the electricity q from B to A is divided by q; $V=W/q$. Or, it is the quotient obtained when the power required to maintain a current between B and A is divided by this current; $V=P/i$.

The *volt* is that difference of potential which, if it exists between A and B, makes it necessary that 1 j of work be done in moving 1 coulomb of electricity from B to A; or that 1 w of power be expended in maintaining 1 amp of current between B and A.

Resistance. The resistance of a conductor AB is the quotient obtained when the potential difference between the cross sections A and B is divided by the unvarying current in the conductor; $R=V/i$. It is assumed that no e.m.f. exists in AB.

The *ohm* is the resistance of a conductor AB such that when the current is 1 amp, the potential difference between A and B is 1 v. In practice, the ohm is most accurately established by certain measurements consistent with these and the following definitions. The volt is then established by means of potentiometer measurements.

Electric field is the region (near an electric charge or a charged body) in which there exist forces on charges or charged bodies.

The *electric field strength* at a point is the quotient obtained when the force on a charge of electricity, if placed at that point, is divided by that charge; $E=F/q$. Or, it is the negative of the potential gradient at the point; $E=-dV/dr$. The conditions for these definitions can be realized in free space but not in solids.

The units *newton/coulomb* and *volt/meter* are equivalent and self-explanatory from the definitions.

Capacitance. The capacitance of a body with given surroundings is the quotient obtained when the electricity on the body is divided by the change in potential produced by this electricity; $C=q/V$ or $C=dq/dV$.

The capacitance of a condenser is the quotient obtained when the electricity on one of its plates is divided by the difference of potential of the plates caused by this electricity, it being assumed that an equal charge of opposite sign is on the other plate.

The *farad* is the capacitance of a body such that 1 coulomb of electricity changes its potential by 1 v.

Capacitivity or *dielectric constant*, ϵ, is defined by the relation $F=qq'/4\pi\epsilon r^2$, where q and q' are charges located at points in an isotropic, homogeneous medium of infinite extent, the distance between the charges being r. It may also be defined by the relation $C=\epsilon S/d$, where C is the capacitance of a parallel plate condenser, S the area of

[2] P. Vigoreux and C. E. Webb, *Principles of Electric and Magnetic Measurements*.

one plate, and d the distance between plates assumed very small compared to S. The value of ϵ varies with the medium in which the charges are immersed in the first case, or the medium between the condenser plates in the second.

From the second of the foregoing relations, it is seen that ϵ may be measured in *farads/meter*.

The value of the capacitivity for a vacuum, ϵ_0, may perhaps be more accurately evaluated from the relation $c^2\epsilon_0\mu_0=1$, where c is the speed of light in a vacuum and μ_0 has the value $4\pi\times10^{-7}$ newton/amp.[2] This gives ϵ_0 the value $1/(4\pi 8.98776\times10^9)$ or approximately $1/(4\pi 9\times10^9)$ farad/m.

Relative capacitivity or *specific inductive capacity*, κ, of a substance is the ratio of its (absolute) capacitivity to the capacitivity for free space; $\kappa=\epsilon/\epsilon_0$. To bring out more clearly the physical meaning of κ, it could be defined as the ratio of the capacitance of a condenser with a given substance as dielectric to its capacitance with vacuum as dielectric.

Magnetic field is the region (near a magnet or a conductor carrying a current) in which there exist forces on magnets or on conductors carrying currents.

Magnetic field strength, H, at a point P is defined in terms of the current capable of producing it. At the center of a long solenoid, it is $H=Ni/l$, where N is the number of turns of wire, each carrying the current i, and l is the length of the solenoid.

The unit, *ampere-turn per meter*, is self-explanatory from the foregoing equation.

A more general relation which would yield the foregoing equation is $H=\int idl \sin\theta/4\pi r^2$, where dl is the length of an element of conductor carrying current i, r is the distance from P to dl, and θ is the angle between dl and r. The field at P is at right angles to the plane of r and dl, and in a direction found by the right-hand rule. The medium surrounding the current must be isotropic and homogeneous.

Magnetic induction or *magnetic flux density*, B, at a point is defined by the equation $dF=Bidl \sin\theta$, where dF is the force on length dl of a conductor carrying a current i, and θ is the angle between the direction of B and the conductor.

Magnetic flux, ϕ, through an area is the product BS, where B is uniform and normal to the area S.

The unit of ϕ is the *weber;* and the unit of B is the *weber/meter*^{2}, or the *newton/meter ampere-turn*. It follows that, if a wire is carrying a current of 1 amp in a region where the magnetic induction is 1 weber/m^2, uniform and normal to the wire, there will be a force of 1 newton on each meter of the wire.

Alternative definitions of ϕ and B follow.

Magnetic flux is defined from the equation, $Nd\phi/dt=-V$, where V is the e.m.f. induced in a coil of N turns when the rate of change of flux in the coil is $d\phi/dt$. The *weber* is that magnetic flux which, if introduced into a coil of 1 turn at a uniform rate during 1 sec, will induce an e.m.f. of 1 v in the coil.

Magnetic induction is defined by the equation, $B=\phi/S$, where ϕ is the flux normal to the area S. The unit is the *weber/meter*.[2]

Inductivity or *permeability*, μ, is the quotient B/H. With B in webers/meters^2 and H in ampere-turns/meter, the unit is *weber/meter ampere-turn*. From the definitions of B, H and i, the value of μ for free space[3] (μ_0) is $4\pi\times10^{-7}$ weber/m amp-turn.

Relative inductivity or *relative permeability*, μ_r, is the ratio μ/μ_0 of the inductivity of the medium considered to that for free space.[4]

It may be noted that ϵ_0 and μ_0 are dimensional constants which play a role somewhat analogous to the constant in Newton's law of gravitation. In any case, μ may be replaced by $\mu_r\mu_0$ and ϵ by $\kappa\epsilon_0$, where μ_r and κ are unity for free space and take on the usual values for other mediums.

Inductance or *coefficient of self-induction*, $\mathfrak{L}$, is defined by the equation, $\mathfrak{L}di/dt=-V$, where di/dt is the time rate of change of current in a circuit and V is the resulting e.m.f. The negative sign signifies that, with an increasing current, the induced e.m.f. is in the opposite direction to the current.

The unit of inductance is the *henry*. It is the inductance of a circuit or part of a circuit such that a back e.m.f. of 1 v is induced when the current in the circuit is changing at the rate of 1 amp/sec.

Magnetic moment, M, of a magnet is defined by the equation $MH\sin\theta=L$, where L is the torque experienced by the magnet in the uniform field of strength H, and θ the angle that the magnet is displaced from its equilibrium position (or the angle between the direction of H and the direction of magnetization of the magnet.)[5] If L is expressed in newton-meters and H in ampere-turns/meter, the unit for M is *newton meter*^{2}*/ampere-turns*.

The *pole strength*, p, of a magnet is the quotient obtained when its magnetic moment is divided by the distance between its poles (assumed as points); $p=M/l$. If the magnet is a long thin bar uniformly magnetized in the direction of its length, the distance between the poles will be the length of the bar. Otherwise, the poles will be distributed over the surface, and cannot in general be considered as at particular points distance l apart.

It can be shown from the foregoing that the force F on a pole of strength p, in a magnetic field H, is given by pH.

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[2] Consider the two wires carrying currents i_1 and i_2 as in the definition of the ampere. From the definition of H, we find for the value of H at the second wire, $i_1/2\pi r$. From the definition of μ, $B=\mu H$. From the definition of B, the force F on the second wire is Bi_2l. Substituting in the last equation, we have $F=\mu(i_1/2\pi r)i_2l$. But when i_1 and i_2 are each 1 amp and l and r are each 1 m, the force F was, by the definition of the ampere, 2×10^{-7} newton. Therefore, μ in this case is $4\pi\times10^{-7}$ newton/amp.^{2}

[4] This choice of symbols, while following closely the recommendations of the I.E.C., is not altogether satisfactory. Another suggestion is μ instead of μ_r, ν or γ for μ, and ν_0 or γ_0 for μ_0.

[5] Some writers prefer to use the term "magnetic field strength" for the quantity B which we have called *magnetic induction*. Moreover, if magnetic moment is then defined as the torque per unit magnetic field, its defining equation becomes $L=MB\sin\theta$ instead of $L=MH\sin\theta$. The two definitions for magnetic moment differ by the factor μ, and this is also the case for the definitions of intensity of magnetization and pole strength. The magnetic moment of a circular current is, in this case, iS instead of μiS; and Coulomb's law becomes $F=\mu pp'/4\pi r^2$ instead of $F=pp'/4\pi\mu r^2$. In the c.g.s. electromagnetic system, these differences in usage would not usually be apparent since μ_0 is unity; but in the m.k.s. system μ_0 is $4\pi\times10^{-7}$.

Also, assuming conservation of energy, the magnetic induction at a distance r from an isolated pole is given by $B=p/4\pi r^2$, and also $H=p/4\pi\mu r^2$.

It follows that the magnetic flux from a unit pole is 1 weber. Pole strength may be indicated in terms of the flux it produces, and, therefore, the *weber* may be used as the unit of pole strength as well as the unit of flux. (This is analogous to the use of the lumen as a unit of average luminous intensity of a light source as well as a unit of the luminous flux produced.)

From $F=pH$, it is apparent that another name for the unit of H is the *newton/weber*. This is equivalent to the ampere-turn/meter.

Returning to *magnetic moment*, it is seen that another name for the unit is *weber-meter*.

Intensity of magnetization, I, of a substance is the magnetic moment per unit volume; $I=M/V$. This is equivalent to pole strength per unit of area normal to the direction of the magnetization. The unit of I is the *weber/meter*.[2]

B and H in iron or other material. The definitions of B and H as given are not readily applicable to determine the values of these quantities inside a piece of magnetic material. Inside the material, these quantities are defined such that the component of B normal to a boundary does not change in crossing the boundary, and the tangential component of H does not change in crossing the boundary. This is equivalent to stating that B in a material is equal to the value of B in a thin slot in the material transverse to the direction of B, and H in the material is the same as H in a slender longitudinal cavity.

As an illustration, consider the Rowland ring as used in the determination of B and H in iron. Since at the surface of the iron there is no component of H normal to the surface, the total value of H is the same inside and just outside the iron. This can be calculated from the current in the primary winding. The value of B outside the iron, however, gives no indication of its value inside. But the change in B can be measured by means of the induced currents in the secondary coil, a method that follows directly from one definition of magnetic flux and of B.

As another illustration, suppose it is desired to find B and H near the center of a straight bar magnet. A search coil wound around the middle of the magnet and suddenly slipped off would serve to measure B. Outside the magnet, B and H are related by the known constant μ_0, so that, if B is measured here by a search coil, H is also known. Or H may be measured by means of a small compass, comparing the value produced by the magnet with that produced by a known current at a given distance. At the location considered near the middle of the magnet, H is found to be parallel to the magnet, so that the value just inside is identical with that just outside. It will be seen that H inside a permanent magnet near the middle is in the reverse direction to B, and μ is therefore negative.

It is often convenient to consider separately the factors contributing to the value of the magnetic induction inside a piece of magnetic material. The equation $B=\mu_0H+I$ separates the effect I due to the intensity of magnetization at the point considered, and the effect μ_0H due to the magnetic field H. The H, as in the case of the Rowland ring, may be produced only by the current in the external circuit; or, as in the case of the bar magnet, it may be produced only by the free poles of the magnet itself.

Electric displacement, D, is the product of the electric field and the capacitivity or dielectric constant; $D=\epsilon E$. The unit is the *coulomb/meter*^{2}.

D and E in a dielectric. When dealing with a medium not of infinite extent, it is necessary to give further definitions, just as was the case in magnetic materials. Inside a dielectric, D is defined such that its normal component does not change in passing through the boundary, and E such that its tangential component does not change at the boundary. This is equivalent to saying that D in a dielectric is equal to its value in a thin transverse slot, and E in a dielectric is equal to its value in a slender longitudinal slot in the dielectric.

Polarization, P, of a dielectric is the electric moment per unit volume, or the polarization charge per unit of area normal to P. The unit is the *coulomb/meter*^{2}.

In the equation, $D=\epsilon_0E+P$, the displacement is considered as made up of two parts, P being that due to the polarization of the dielectric at the point considered, and ϵ_0E that due to the electric field. It is easily seen that, in a parallel plate condenser, the displacement in the dielectric is the same as in the space between the dielectric and either condenser plate, and is also equal to the surface density of charge on the condenser plate. The difference between the surface density of charge on the plate and the surface density of polarization charge on the dielectric gives the term ϵ_0E.

TABLE I. *Some fundamental equations expressed in four different systems.*

RATIONALIZED m.k.s.	NONRATIONALIZED m.k.s.	HEAVISIDE-LORENTZ (RATIONALIZED)	GAUSSIAN (NONRATIONALIZED)
$F=qq'/4\pi\epsilon r^2$	$F=qq'/\epsilon r^2$	$F=qq'/4\pi r^2$	$F=qq'/r^2$
$dH=idl\sin\theta/4\pi r^2$	$dH=idl\sin\theta/r^2$	$dH=idl\sin\theta/4\pi cr^2$	$dH=idl\sin\theta/cr^2$
$F=pp'/4\pi\mu r^2$	$F=pp'/\mu r^2$	$F=pp'/4\pi r^2$	$F=pp'/r^2$
$\nabla\cdot\mathbf{D}=\rho$	$\nabla\cdot\mathbf{D}=4\pi\rho$	$\nabla\cdot\mathbf{D}=\rho$	$\nabla\cdot\mathbf{D}=4\pi\rho$
$\nabla\cdot\mathbf{B}=0$	$\nabla\cdot\mathbf{B}=0$	$\nabla\cdot\mathbf{B}=0$	$\nabla\cdot\mathbf{B}=0$
$\nabla\times\mathbf{E}=-\dot{\mathbf{B}}$	$\nabla\times\mathbf{E}=-\dot{\mathbf{B}}$	$\nabla\times\mathbf{E}(=-1/c)\dot{\mathbf{B}}$	$\nabla\times\mathbf{E}=-(1/c)\dot{\mathbf{B}}$
$\nabla\times\mathbf{H}=\dot{\mathbf{D}}+\rho\mathbf{u}$	$\nabla\times\mathbf{H}=\dot{\mathbf{D}}+4\pi\rho\mathbf{u}$	$\nabla\times\mathbf{H}=1/c(\mathbf{D}+\rho\mathbf{u})$	$\nabla\times\mathbf{H}=1/c(\mathbf{D}+4\pi\rho\mathbf{u})$
$\mathbf{B}=\mu_0\mathbf{H}+\mathbf{I}=\mu\mathbf{H}$	$\mathbf{B}=\mu_0\mathbf{H}+4\pi\mathbf{I}=\mu\mathbf{H}$	$\mathbf{B}=\mathbf{H}+\mathbf{I}=\mu\mathbf{H}$	$\mathbf{B}=\mathbf{H}+4\pi\mathbf{I}=\mu\mathbf{H}$
$\mathbf{D}=\epsilon_0\mathbf{E}+\mathbf{P}=\epsilon\mathbf{E}$	$\mathbf{D}=\epsilon_0\mathbf{E}+4\pi\mathbf{P}=\epsilon\mathbf{E}$	$\mathbf{D}=\mathbf{E}+\mathbf{P}=\kappa\mathbf{E}$	$\mathbf{D}=\mathbf{E}+4\pi\mathbf{P}=\kappa\mathbf{E}$
$u=1/(\epsilon\mu)^{\frac{1}{2}}$	$u=1/(\epsilon\mu)^{\frac{1}{2}}$	$u=c/(\kappa\mu)^{\frac{1}{2}}$	$u=c/(\kappa\mu)^{\frac{1}{2}}$

TABLE II. *Some common formulas expressed in the two m.k.s. systems.*

QUANTITY	RATIONALIZED	NONRATIONALIZED
Capacitance of parallel plate condenser	$C=\epsilon A/d$	$C=\epsilon A/4\pi d$
Capacitance of sphere	$C=4\pi\epsilon r$	$C=\epsilon r$
Capacitance of cylindrical condenser	$C=2\pi\epsilon l/(\ln r/r')$	$C=\epsilon l/(2\ln r/r')$
Magnetic field at center of long solenoid	$H=Ni/l$	$H=4\pi Ni/l$
Magnetic field at center of flat coil	$H=Ni/2r$	$H=2\pi Ni/r$
Magnetic field produced by long wire	$H=i/2\pi r$	$H=2i/r$
Energy density in magnetic field	$W=BH/2$	$W=BH/8\pi$
Energy density in electric field	$W=DE/2$	$W=DE/8\pi$

The speed of an electromagnetic wave is given by $c=1/(\epsilon_0\mu_0)^{\frac{1}{2}}$ for free space, or $u=1/(\epsilon\mu)^{\frac{1}{2}}$ for any medium. The equation for c would appear as an experimental relation, if we adhere to previous definitions. There seems to be good evidence that the equation is exact, however, and it may, therefore, be used to evaluate ϵ_0 as was previously mentioned.

RATIONALIZATION

The question of rationalization of m.k.s. units has been left open by international committees. Opinion seems to be rather evenly divided on the subject, with perhaps a majority of those who have studied the matter carefully in favor of rationalization. It seems to this committee that it is not so important which way the matter is decided, but that it is important to have it decided one way or the other at this time. It would be unfortunate to have two forms of the m.k.s. system come into use. We have, therefore, listed definitions only for the rationalized units.

The argument most frequently given for the nonrationalized system is that more people are familiar with it; the c.g.s. electrostatic and electromagnetic systems as usually given are nonrationalized. This is an important consideration; but, at the time of the extension of the m.k.s. system to cover the fields of electrostatics and magnetism, the added change involved is not serious.

Tables I and II illustrate the distinction between rationalized and nonrationalized systems. It will be noted that in a rationalized system the 4π occurs in places where it might be expected, that is, where spherical symmetry exists; 2π occurs where there is circular or cylindrical symmetry; and there is no π where there is rectangular symmetry. The differences appear primarily where electric or magnetic fields are involved.

In a rationalized m.k.s. system, it is not necessary to have many new names for units, as is seen by referring to the list of definitions and units given. In a nonrationalized m.k.s. system, however, new names would be needed for the units of magnetic field, magnetomotive force, magnet pole, and electric displacement. The units ampere, volt, ohm, farad, henry, coulomb, weber, etc., would remain in either m.k.s. system.

The numerical calculations involved in most problems is the same in each kind of system.

As an illustration, suppose it is desired to find the capacitance in farads of a parallel plate condenser in which the area of one plate is 200 cm², the distance between plates 0.4 mm, and the relative capacitivity of the dielectric 8. Using first $C=\epsilon A/d=\kappa\epsilon_0 A/d$ and assuming ϵ_0 to be $1/4\pi\times9\times10^9$ farad/m, we obtain

$$C=\frac{8\times\dfrac{1}{4\pi\times9\times10^9}\dfrac{\text{farad}}{\text{m}}\times0.02\ \text{m}^2}{0.0004\ \text{m}}=\frac{8\times0.02}{4\pi9\times10^9\times0.0004}\text{farad}.$$

Next, using $C=\epsilon A/4\pi d=\kappa\epsilon_0 A/4\pi d$, where ϵ_0 is now approximately $1/9\times10^9$ (no name for unit), we have

$$C=\frac{8\times1/(9\times10^9)\times0.02}{4\pi\times0.0004}=\frac{8\times0.02}{4\pi9\times10^9\times0.0004}\text{farad}.$$

As another illustration, suppose it is desired to find the flux density B inside an air core solenoid 2 m long with 5000 turns of wire carrying 0.4 amp. Using the rationalized form $H=Ni/l$, we have $H=5000$ turns$\times0.4$ amp/2 m $=1000$ amp-turn/m and $B=\mu H$, where $\mu=\mu_0=4\pi\times10^{-7}$ weber/m amp-turn; therefore, $B=4\pi\times10^{-7}\times1000=4\pi\times10^{-4}$ weber/m². Next, using $H=4\pi Ni/l$, we have $H=\dfrac{4\pi\times5000\ \text{turns}\times0.4\ \text{amp}}{2\ \text{m}}=4\pi\times1000$ (no name for unit), and $B=\mu H$ where $\mu=\mu_0=10^{-7}$ in nonrationalized units; therefore, $B=10^{-7}\times4\pi\times1000=4\pi\times10^{-4}$ weber/m². It will be noted in the last example that the rationalized form of equation offers some advantage where H alone is to be computed, but that this advantage is lost when B is calculated.

DIMENSIONS

It is with some hesitancy that such a controversial subject as dimensions is mentioned here.[6] *If a system of units with definitions and defining*

[6] For a clear presentation of the subject and for further references see R. T. Birge, Am. Phys. Teacher 2, 41 (1934).

equations is agreed upon, the dimensions will take care of themselves. There are a few misapprehensions which are so common and have caused so much trouble, however, that they should be given some attention.

It is often assumed that the dimensions of a physical quantity tell us the "nature" of the quantity and *must* make a unique distinction among quantities of different nature. It is sometimes stated that the dimensions of dielectric constant and permeability are at present unknown, but that more knowledge may eventually enable us to ascertain their dimensions. Length, mass, and time are often considered as the only possible fundamental quantities, and as such cannot be defined. Misconceptions such as these are usually acquired early in one's education and are held with a religious fervor. The remedy lies simply in the omission of such statements or inferences from our textbooks and from our teaching.

Let us consider how well the dimensions determine the "nature" of a quantity. Following the generally accepted definitions and the *usual method of assigning dimensions*, we find that the volume modulus of elasticity, the shear modulus, and Young's modulus all have the same dimensions, and these dimensions are the same as for the corresponding stress in each case; also, that the various temperature coefficients, such as those for length, volume, pressure, speed of sound, electrical resistance, etc., all have the dimensions of the reciprocal of temperature.

On the other hand, density has dimensions and specific gravity has none, but both give us a measure of essentially the same physical property. The latter makes use of a standard substance, usually water at a specified temperature; and the former makes use of standards of length, or volume, and mass. The term specific heat is sometimes used for the quantity having no dimensions and sometimes for one having the dimensions of heat divided by mass and temperature; yet, in each case, the same physical property is being measured. Electric current as defined in the electrostatic system has different dimensions from electric current as defined in the electromagnetic system, but we presume we are measuring the same thing in each case.

From these various examples, it is seen that we would require a very special definition of the phrase "nature of a physical quantity," if we were to conclude that the dimensions determine, or are determined by, the nature of the quantity.

It may be well to recall the way in which dimensions are established. Suppose we first consider volume, assuming that length, its method of measurement, and a unit of length have previously been agreed upon. The concept which we will call volume is found, experimentally, to be proportional to the product of three lengths mutually perpendicular; $v = al_1l_2l_3$. This might be considered *only* an experimental relation and some unit of volume chosen which was independent of this equation. In this case, the proportionality factor a would have the dimensions of volume divided by length cubed. However, it is customary to use the foregoing equation in defining volume, and to make a unity and dimensionless, thus giving volume the dimensions of length cubed. The chemist, however, does not usually make use of this unit and method of measurement in measuirng the volume of a liquid. He more generally uses the liter as his unit. For the purpose of this argument, let us use the term *capacity*, C, for the quantity which is measured in liters. The liter is defined as the capacity, at the temperature of its greatest density, of a body of water having a mass of 1 kg. Experimentally it is found that capacity is proportional to volume; $C = bv$. If C is measured in milliliters and v in cubic centimeters, b is nearly, but not exactly, unity. It would not be illogical to give b the dimensions of capacity divided by volume, but this is not usually done. Instead, we consider b as dimensionless even though not unity, and C has the dimensions of v.

This illustration serves to show that the dimensions of a quantity depend upon the primary quantities chosen in terms of which the dimensions are to be expressed, the defining equations used, and also certain arbitrary assumptions regarding factors of proportionality.

The situation in mechanics differs markedly from that in other fields, especially electricity. In mechanics, there is one set of defining equations and assumptions which is generally accepted, so that there is very little argument about dimensions. The systems of units differ only in the size of the units employed or the standards adopted, and not in the relations among the several quantities. On the other hand, the systems of electrical units differ in their defining equations, or in the assumptions made, or in both. This causes differences in the dimensions of like-named quantities in the various systems. It also may be added that it causes ambiguity when one merely refers to a particular quantity, such as magnetic induction, without specifying the system of definitions.

In the field of heat, the form of the equations is in general the same for all systems of units, but different assumptions are sometimes made regarding the character of proportionality constants. Sometimes, length, mass, time, temperature, and heat are all used as primary or fundamental quantities, especially in the introduction to the subject. In this case, the equation $W = JH$ is assumed to be an experimental relation only, and J has the dimensions of work divided by heat. Or J may be considered dimensionless and W and H each measured in either mechanical or heat units. The choice made does not affect the physical interpretations. It may be more convenient in certain cases to be able to distinguish between W and H by their dimensions, in which case J must be carried as a dimensional constant. In other cases, especially in theoretical work, the J may be merely a nuisance and can well be omitted.

The m.k.s. system which has been described for electrical quantities permits us to assume either three or four primary quantities, while the Gaussian and Heaviside-Lorentz systems permit three. One result of having four primary quantities is that a larger number of quantities are distinguished from each other by their dimensions. This, as was shown, is not necessary, but is considered a very useful feature. As already pointed out, there is no necessary relation between dimensions and the nature of a quantity. A well-chosen system of dimensions can help greatly, however, in keeping our ideas straight. For example, to measure speeds in meters per second and give speed the dimensions L/T, is an aid in keeping clearly in mind the fact that speed is something that involves distance directly and time inversely.

On the other hand, the Gaussian or the Heaviside-Lorentz system has certain advantages for theoretical work. The equations are somewhat simplified by replacing the two dimensional factors ϵ and μ of the m.k.s. system by the one dimensional constant c. It should also be pointed out that there is no change necessary in the form of the equations in the m.k.s. system if three rather than four fundamental units are assumed. One merely assumes μ (but not ϵ) to be dimensionless, and the ampere, therefore, has the same dimensions as the square root of the newton.

Some confusion also arises from the use of the word "absolute" as applied to a system of units. The word appears with a variety of implied meanings, the reader often assuming a different meaning from that of the writer. An absolute system is regarded by some authors as one that uses the dyne or the poundal as the unit of force, as distinguished from a gravitational system which uses the gram of force or the pound of force. Other authors regard it as a system based on only length, mass, and time as fundamentals; or on an assumed smallest number of fundamentals; or on any small number of fundamentals. Still others regard it as a system based on unchanging standards (the assumption being made that there are such). Usually some combination of these meanings is given or implied. Consequently, it may be well to avoid using the term unless it is given a restricted or exact meaning.

It is sometimes stated that the British Engineering System is based on a variable force unit. This, of course, would be the case if one used only the approximate definition of the pound of force as the weight of a body whose mass is one pound without regard to location. But if one uses the more exact definition that the pound of force is the weight of a body of one pound mass at a place where g has a particular value, then the pound of force becomes as unchanging as the units of length and mass. The weight of a body expressed in pounds of force then varies with the elevation as it should.

In conclusion, it may be well to emphasize the fact that the use of the system of units here recommended does not impose undue restrictions on the methods of presentation of the subject of physics; the usual variety of interpretations is still possible. The particular system of units employed does not affect the physical principles which are to be described or explained. If one desires to give reasonably complete definitions of all the units as the subject is first presented, then certain orders of presentation of the material are preferable to others. But there is still considerable room for choice. For example, it has been found reasonably satisfactory to teach only the m.k.s. system in electricity and still use an old and well-known text; the changes involved were made in a few mimeographed notes.

It is not likely that any proposed system of units will appear best in all its details to any considerable number of individuals. Our proposals are made after conferences with physicists and electrical engineers of varied interests and points of view; and it is believed that agreement along these lines is quite possible and would not cause hardship on any groups or individuals. The advantages to be gained by fewer systems and more uniformity are so great that it is hoped this report will receive favorable consideration.

The Committee on Electric and Magnetic Units of the American Association of Physics Teachers
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The Baldwin Piano Company, Cincinnati, Ohio

THE equation for the current between two electrodes at a potential difference when the current is space-charge limited was first set forth by Child for positive ions. This equation, known as Child's law, is obtained by combining Poisson's equation, which defines the potential distribution V due to a charge of density ρ,

$$d^2V/dx^2 = -4\pi\rho,$$

the energy equation, giving the speed v which a particle of mass m and charge e attains on falling through a potential difference V,

$$Ve = \tfrac{1}{2}mv^2,$$

and the equation defining current density,

$$i = \rho v,$$

and then integrating twice the resulting equation,

$$\frac{d^2V}{dx^2} = 4\pi i\left(\frac{m}{2e}\right)^{\frac{1}{2}}\frac{1}{(V)^{\frac{1}{2}}};$$

this gives

$$i = \frac{1}{9\pi}\left(\frac{2e}{m}\right)^{\frac{1}{2}}\frac{V^{\frac{3}{2}}}{d^2}, \qquad (1)$$

where d is the distance between electrodes. Although Eq. (1) is valid only for parallel, plane electrodes, a similar equation results for cylindrical electrodes, namely

$$i = \frac{2\sqrt{2}}{9}\left(\frac{e}{m}\right)^{\frac{1}{2}}\frac{V^{\frac{3}{2}}}{r_s f(r_s/r_c)}, \qquad (2)$$

where r_s and r_c are the radii of the outer and inner electrodes, respectively, and the function $f(r_s/r_c)$ approximates unity if $r_s \gg r_c$.

Although derived for positive ions, this three-halves power law is equally valid for electron currents, provided m is made the electronic mass. The usual method of experimentally verifying this relation for electron currents is to measure the space-charge limited current of a thermionic tube for various applied voltages. For tungsten filaments, this method is satisfactory, but for thoriated tungsten and oxide coated filaments, the results tend to deviate from those expected.

The use of a three-electrode gas discharge tube such as the 885 permits, however, a simple and convincing demonstration of the three-halves power law for positive ions. It is well known that the discharge in such a tube can be extinguished by making the grid sufficiently negative. On initiation of the arc, the grid is immersed in the plasma and a positive ion sheath forms around the negative grid wires. The thickness of the sheath depends upon the amount of negative voltage applied to the grid and on the arc current density. However, at any fixed value of arc current (anode current), as the grid is made more and more negative, the sheath becomes thicker and thicker, until a point is reached where the sheaths on adjacent grid wires begin to overlap, thus effectively "throttling" the plasma and interrupting the arc. Since the spacing between grid wires is fixed, the sheath thickness *at the instant of arc extinction* is constant and independent of arc current density. For high densities, the applied grid voltage will, of necessity, be more negative than for low densities, but the sheath *thickness* will be the same for both.

One boundary of the positive ion sheath will be the grid wire, the other will be the plasma. The potential distribution curve at the plasma boundary cannot bend abruptly, as there can

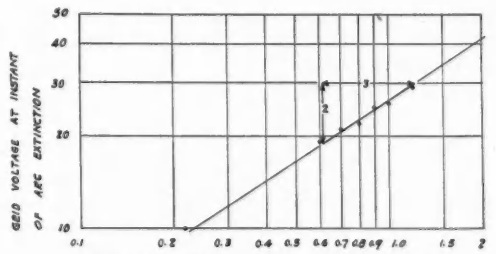

FIG. 1. Evidence that the grid current and voltage at the instant of arc extinction in a gas triode conform to Child's law.

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be no surface charge there, and the conditions at this boundary will, therefore, correspond to those at the cathode of a space-charge limited *electron* current. The current through the sheath will accordingly be a space-charge limited positive ion current and will conform to Child's law. For constant sheath thickness, the current density or current will depend only upon the voltage and will be proportional to the three-halves power of this voltage.

If the grid current and grid voltage at the instant of arc extinction are measured for various values of the anode current and these values plotted, the plotted points should lie along the curve

$$I_g = K V_g^{\frac{3}{2}},$$

where K is a proportionality constant. If the logarithms of these values are plotted, they should lie along a straight line of slope $\frac{3}{2}$. From Fig. 1, which shows the plot of a run made on an argon-filled gas triode, this is observed to be the case.

Lens Testing on a Student Spectrometer

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UNDERGRADUATE courses in optics and photography usually include mention of several lens aberrations, but due to the complicated mathematics involved in all except chromatic aberration, the subject is dropped without further treatment. The writer has found, however, that photography enthusiasts, particularly if they own expensive lenses, are intensely interested in measuring the astigmatism, field curvature and other errors of their lenses, though they may not understand all the reasons for such errors.

Two pieces (Fig. 1) have been constructed to replace the prism table and collimator of a student spectrometer and thereby make of it a simple, reasonably accurate lens testing device. Spectrometer attachments of a similar design and using the same principles were constructed several years ago by Professor I. S. Bowen for use in the optics laboratory of the California Institute of Technology, but no report concerning them has been made by him. The prism table is replaced by a nodal slide consisting of a sleeve for the central post, an attached horizontal rectangular plate with side ways, and two grooved uprights mounted on a second horizontal plate machined to fit the ways. A thin metal sheet cut to fit between the grooved uprights is drilled to take a particular camera lens and shutter; this sheet alone must be replaced in the study of different lenses. A simple lens may be fastened to any sheet with a few drops of collodion or shellac; a camera lens in its shutter requires its special sleeve nut to fasten it securely to the upright sheet.

The collimator replacement, herein called the *naometer*, consists of a slotted tube carrying the scale and slide of a vernier caliper. The slot of the present equipment allows measurement of focal distances between 3.6 and 17.5 cm. Cross hairs, vertical and horizontal, are shellacked to a small ring soldered to the slide of the vernier caliper. Much of the tube is cut away in order that the cross hairs may be well illuminated. To insure that the vernier reads directly the distance from the cross hairs to the axis of rotation of the nodal slide, care must be taken to fix the naometer accurately in the collimator sling. Fig. 2 shows a Gaertner student spectrometer with the two pieces attached. It is unfortunate that the central post of this spectrometer was so tall, for it necessitated trimming in order to place even moderate sized camera shutters sufficiently low to align the axes of lens and telescope.

After the telescope is focused for parallel rays and aligned roughly with the naometer, the lens plate with lens attached is lowered into its

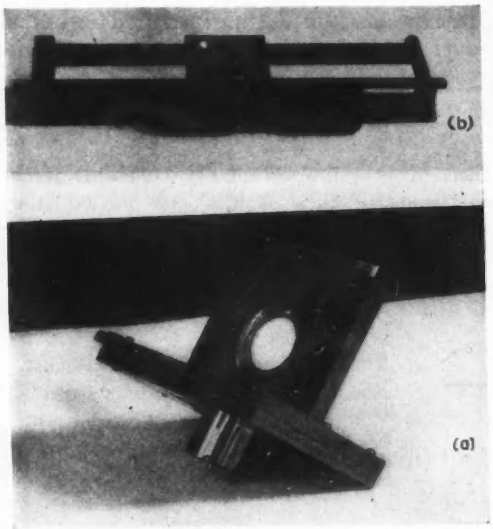

FIG. 1. (*a*) Prism table replacement; (*b*) collimator replacement.

groove and the lens table turned until the lens axis is along the telescope axis. Use is now made of the property of nodal points utilized on nodal slides, a property customarily stated thus: if a lens is rotated through a small angle about the emergent nodal point, the image of a distant object does not move.[1] Since the light is propagated in this experiment in a direction opposite to that actually used by a camera, it is the converse of the foregoing proposition that here applies; namely, if a lens is rotated through a small angle about the *immergent* nodal point, rays coming from a point source in the focal plane and emerging from the lens retain their original direction. The cross hairs of the naometer are moved into focus and the lens table rotated through a small angle. When the image of these cross hairs as formed by the telescope does not remain fixed with respect to the cross hairs of the telescope eyepiece, the nodal slide is moved slightly in the ways, the naometer cross hairs again brought into focus, and the process repeated. Vertical adjustment is easily obtained by sliding the plate which holds the lens, and after the nodal point is located at the center of

[1] Robertson, *Introduction to Physical Optics*, ed. 2, problem 19, p. 106; Monk, *Light Principles and Experiments*, p. 347.

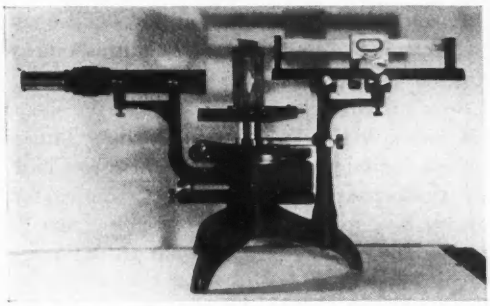

FIG. 2. Spectrometer equipped for lens testing.

the spectrometer and the ways locked, final alignment of the telescope may be made. An approximate optical axis for the lens may be found by turning the lens to each side until the light is cut off and choosing the angle-setting halfway between these field boundaries. A plane mirror fastened temporarily to the lens mount and used with the Gauss eyepiece of the telescope also gives an approximate axis.

Astigmatism and field curvature studies are made by leaving the telescope and naometer in line. The horizontal hair (radial or primary rays) and vertical hair (tangential, meridional or secondary rays) of the naometer are focused individually. Then the lens is turned through some determined angle and the focusing repeated. Radial and tangential focal distances are plotted on large polar coordinate paper. With

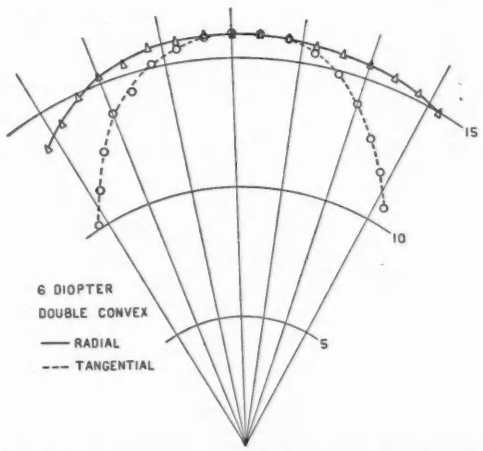

FIG. 3. Polar coordinate graph of simple lens astigmatism and field curvature.

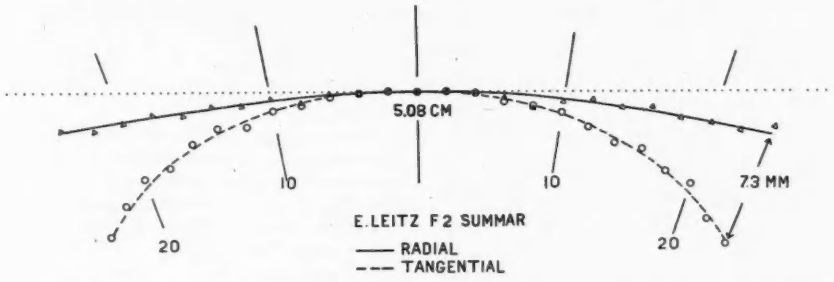

FIG. 4. Polar coordinate graph of camera lens astigmatism and field curvature. The polar axis is located below the figure. The dotted line shows the position of the film.

5-cm lenses of good quality, readings are duplicative to about 0.1 mm near the center of the field and 0.3 mm near the edge. Figs. 3 and 4 show astigmatism studies made by students. Data collected for these experiments are extremely honest since it is impossible to read the vernier while focusing. Among the more interesting "discoveries" by the students are a relatively large lack of symmetry about the optical axis of many camera lenses in any plane tested, and a decided difference in curves taken for different planes through the optical axis, probably due to poor threading of the lens mounts in the shutters.

In studying astigmatism another common lens error becomes manifest. This aberration, distortion, gives rise to the well-known pin cushion or barrel-shaped image of a rectangular object. As the angle between lens and telescope axes is increased beyond the small angle used in fixing the nodal point, it is usually observed that the vertical hair of the naometer no longer comes to focus at the intersection of the telescope cross hairs. Such deviation shows that incident angles are not reproduced faithfully in the image space. A good measure of distortion can easily be made with this apparatus by locking the lens table at some determined angle, as in testing for astigmatism, and then using the slow motion screw of the telescope to obtain coincidence between the intersection of the telescope cross hairs and the image of the vertical hair of the naometer. This small angle β through which the telescope is turned is recorded. Before the lens table is rotated to another position, the telescope must be returned to alignment with the naometer. On a photographic plate, distortion causes the image of a distant point to be displaced from its proper position. The displacement is simply $\Delta = F\beta/\cos^2\theta$, where F is the focal length of the lens along its axis, θ is the incident angle, and β is the distortion angle expressed in radians.

Spherical aberration of lenses with apertures less than that of the telescope may be studied with the aid of suitable subsidiary ring apertures, but there is likely to be confusion as to whether it is the aberration of the telescope objective or of the test lens that is actually being determined. Illuminating the cross hairs of the naometer with light passed through various filters will permit a study of chromatic aberration, although here again, except for the particular colors for which the telescope is corrected, there is likely to be confusion. If the telescope is achromatic, fairly good results are obtainable. Focal length may be plotted against wave-length of maximum transmission for the various filters.

Rack-and-pinion or screw adjustment would be helpful in accurately placing the immergent nodal point at the spectrometer center, and a vernier scale on the ways and upper plane of the nodal slide would permit good measurement of nodal point separation.

The word 'impossible' is not in my dictionary.—Röntgen.

Acoustic Experiments in the Teaching of Optics[1]

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IT is the opinion of the writer that the usual elementary courses in physics do not lay an adequate foundation in the subject of wave propagation. One reason for this is that we have depended upon optics as the main vehicle for teaching that subject even though it is not well adapted to the task. Many topics in optics cannot be taught without great difficulty because it is almost impossible to give the beginner an adequate experimental background, particularly in those fields where the phenomena of wave propagation are under consideration explicitly.

Five such inherent difficulties are: (1) the psychological handicaps due to the strangeness, and apparent remoteness from ordinary experience, of the subject of undulatory optics; (2) the relatively high degree of manipulative skill required for successful experimentation; (3) the high cost of apparatus; (4) the pedagogically unfortunate fact that many conclusions cannot be checked by direct measurement; (5) the fact that many phenomena and experimental situations of theoretical importance from the viewpoint of the broad subject of wave propagation, cannot be illustrated experimentally *at all* in optics.[2]

Optics courses can be greatly enriched, they can be made to contribute more to the student's understanding of the fundamental subject of wave propagation, and the difficulties enumerated above overcome to a large extent, by introducing acoustical experiments into optics.

APPARATUS[3]

The source is a Galton whistle, actuated by a continuous supply of air. It is convenient, is very nearly a point source, gives a rather pure tone, and allows continuous variation of the frequency. Waves produced are approximately 2 to 8 cm in length. Experience has shown that tones having wave-lengths of 3 to 4 cm are most desirable. Slit widths and film thicknesses can then actually be made smaller than the wave-length without becoming microscopic; or large, relatively, without becoming unwieldy. Furthermore, such sounds have the advantage of still being audible and yet being far enough above the range of most ordinary laboratory noises to facilitate the filtering out of the latter.

The whistle is mounted in, and near the end of, a box to minimize "stray sounds" about the room. Its sides are lined with cotton, about 1 in. thick, to eliminate internal reflection at the walls.[4] Its aperture is large enough to insure a well-defined narrow beam and its length great enough to yield approximately plane waves. Satisfactory dimensions of the box are $30\times45\times120$ cm. Smaller boxes have been used successfully. They are more likely to produce spurious effects, however, and therefore require greater experimental skill and theoretical insight for successful work. For some experiments, the source end of the box is also padded with cotton. For others, there is mounted immediately behind the whistle a plane reflector, perpendicular to, and movable along, the longitudinal axis of the box.[5]

Apertures of various sizes and shapes are cut from thin metal or cardboard sheets, and then mounted in grooves[6] at the open end of the box.

The receiver system used now[7] consists of a small-sized crystal-type microphone, satisfactorily sensitive up to frequencies of 15,000 sec^{-1}; an audiofrequency amplifier, and electrical high pass filter, designed to cut out frequencies below 5800 sec^{-1}; and a cathode-ray oscillograph.

It is important to guard against reflection from the walls or objects in the room. This may be accomplished by means of blankets or other absorbing drapes properly placed.

Other apparatus used in particular experiments will be described briefly below.

EXPERIMENTS

The following is an outline of experiments that have been performed successfully in the writer's laboratory. Some of them have already been described in detail and will be mentioned merely in order to give a complete picture of possibilities. Those that were demonstrated qualitatively in

[1] The first part of this article is an abstract of the lecture, with the same title, delivered at the Indianapolis meeting of the American Association of Physics Teachers, December 28, 1937.

[2] Thus, it is impossible to obtain a true point source, apertures, and reflectors that are small compared to wave-lengths, etc.

[3] The apparatus used by the writer during his demonstration lecture was makeshift in part, because of limitations imposed by transportation difficulties and the absence of lecture room facilities.

[4] Such a box was described earlier; see H. K. Schilling and Wm. Whitson, Am. Phys. Teacher **4**, 28 (1936). In later work the wedge *d*, Fig. 1, was removed and the movable plane reflector, referred to above, substituted for it. When the box is properly "padded" there will be nearly uniform intensity of sound over the entire aperture, except very near the walls of the box where it is greatly reduced.

[5] For a discussion of the effect of such a reflector near a source, see reference 4, p. 30.

[6] See reference 5, Fig. 1, h.

[7] For three years the only receivers used by the writer were sensitive flames. They are satisfactory provided one is not interested in intensity relations.

the writer's lecture[1] are marked by an asterisk. The more important ones of those not included in the two preceding groups will be described in detail in a paper to be published soon.

Huygens' principle

1. *Small circular aperture.* When such an aperture is small compared to the wave-length, it may be considered a point source or may be used to demonstrate how spherical secondary wavelets originate at a point on a wave front.
2. *Small spherical reflector.* A small ball. Illustrates same principle for reflection.
3.* *Narrow slit.* When the width of such a slit is small compared to wave-length, it may be considered a line source. No diffraction pattern.
4. *Narrow reflector.* (a) Solid cylinder with radius small compared to wave-length; same principle as *3*, except for reflection; (b) Tall narrow flame; (c) Water jet.

Young's principle of superposition and interference

1. *Two small circular apertures.* This yields a pure interference pattern and is the analog of Young's experiment. (a) Effect of covering each aperture at minimums and at maximums; (b) effect of change of distance between apertures; (c) effect of change of wave-length.
2. *Two small balls.* Same as *1*, except for reflection.
3.* *Two narrow slits.*[5] Same effects as in *1*.
4. *Two narrow reflectors.* (a)* Solid cylinders; (b) narrow gas flames; (c) water jets.
5. *Multiple narrow slits.* Transmission grating (plane, curved) for which diffraction effect due to slit width need not be considered.
6. *Multiple narrow reflectors.* Same principle as *5*, except for reflection. (a)* Solid reflecting grating; (b) narrow flames reflecting grating.

Interferometer effects

These experiments require the use of total and partial reflectors (corresponding to half-silvered mirrors or reflecting surfaces of transparent mediums). The former are, preferably, rigid metal plates. For the latter, the plates are perforated. The ratio of transparent to opaque area is between 1/3 and 1/5, depending upon the purpose of a particular experiment. They can be mounted on optical benches to facilitate proper orientation, motion, and measurement.

1. *Stationary waves.* (a)* Solid reflector;[4] (b) liquid reflector; (c) gaseous reflector.
2.* *Lloyd mirror.*[4]
3.* *Reflector near, and behind, source.*[4]
4.* *Fresnel mirrors.*[4]
5.* *Thin film.*[4] Analog of soap film or Newton's rings. (a) One surface transparent, the other opaque; (b) both surfaces transparent.
6.* *Michelson interferometer.*[5]
7.* *Fabry-Perot interferometer.*[5]
8. *Other types of interferometers.*[5]

[5] H. K. Schilling, "Acoustical Interferometers," Am. Phys. Teacher 5, 280 (1937).

Diffraction

A. Transmission

1. *Circular apertures.* (a) Variation of intensity along axis; (b) effect of size; number of zones; (c) effect of wave-length.
2. *Annular apertures.* Same effects as in *I-1*.
3.* *Zone plates.* Same effects as in *I-1*.
4.* *Single rectangular aperture.* (a) Effect of width; (b) effect of covering different number of zones at minimum and at maximum.
5. *Multiple rectangular apertures.* Gratings for which slit width must be taken into account. (a) Effect of slit width; (b) effect of gratings space; (c) effect of number of slits.

B. "Shadow" effects

1. *Opaque circular disks and spheres.* Arago bright spot.
2. *Rectangular opaque strips.* Diffraction fringes within geometrical shadow.

C. Reflection. Here a unidirectional microphone is desirable, though not indispensable.

1. *Circular reflector.* (a), (b), (c), same effects as in *I-1*; (c) filtering action of small reflectors.
2. *Annular reflectors.*
3. *Zone plates.*
4. *Phase reversing reflecting zone plates.*
5. *Rectangular reflectors.* Same effects as in *I-4*.
6. *Spherical reflectors.* (a) Diffraction pattern at focus: nature of foci; (b) effect of change of size of reflector upon focal diffraction pattern. (c) effect upon focal diffraction pattern of change of wave-length.
7. *Measurement of angular separation of acoustic binary.* By Michelson's method used on astronomical binary.
8. *Scattering.*

Reflection according to geometrical optics

1. *Large plane reflector.* (a) Solid; (b) gaseous; for example, hot air; (c) liquid, thick layer and very thin film.
2. *Curved reflectors.* (a) Conjugate foci; (b) beams.

Absorption

1. *Reflectors of different materials to demonstrate different absorption coefficients.*
2. *Effect of thickness.*
3. *"Area effect."*
4. *Gas.* Knudsen effect.

Speed of sound[9]

Direct determination by Fizeau's well-known optical method.

Multiple sources

Two or more whistles mounted in sound box.

1. *Beats.*
2. *Visibility curves for interferometers.*
3. *Analysis of spectra consisting of two or more lines.* By (a) single slit; (b) double slit; (c) grating.

[9] H. K. Schilling, Am. Phys. Teacher 4, 206 (1936).

A Lecture Room Determination of the Velocity and e/m of the Electrons in a Cathode-Ray Oscillograph

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AFTER reading the recent article by Bainbridge[1] on the "specific charge" of the electron it occurs to us that readers might be interested in another method which we have used in lectures for several years to determine the velocity and e/m of electrons. Though not of great accuracy, both the observations and calculations involved are so simple as to be suitable for a large class of beginning students.

The apparatus consists of a cathode-ray oscillograph mounted horizontally, halfway between two long straight wires parallel to its axis. A photograph of the outfit is reproduced in Fig 1. It is preferable to have the axis of the oscillograph tube pointing in a north-south (magnetic) direction, but this is probably not essential if the orientation of the lecture room makes it inconvenient. The axis of the oscillograph and the two wires determine a vertical plane and the oscillograph is adjusted so that the electrostatic deflection produced by the plates to be used is exactly in this plane. The wires are connected in series so that the magnetic fields set up between them by the currents are in the same direction, horizontal and perpendicular to the axis of the oscillograph. The cathode-ray beam coming down this axis finds itself in an approximately uniform magnetic field. The south-north component of this field is simply the horizontal component of the earth's field and has no effect since it is parallel to the direction of motion of the electrons. The vertical component is the vertical component of the earth's field and will produce a constant deflection of the beam to the right or left which will not affect the vertical deflections under observation. The effect of the east-west magnetic field set up by the current in the wires will be to bend the electron beam up or down so that the fluorescent spot on the screen of the oscillograph moves up or down. This deflection may be increased or decreased by putting an appropriate voltage on the horizontal plates of the oscillograph.

The quantities to be observed are the position of the fluorescent spot, the current in the wires, the potential across the deflecting plates, and the potential accelerating the electrons from the cathode before they enter the deflecting plates. Our practice has been to record the current in the wires and the deflecting potential on the big meters on the lecture room wall so that the class itself can make the readings. The accelerating potential may also be recorded on a voltmeter readable by the class. The class can see the position of the fluorescent spot well enough to determine fairly accurately when a combination of magnetic and electric fields has succeeded in bringing it back to its undeflected position although the measurement of an actual deflection has to be made by the lecturer. Our procedure is to determine the position of the fluorescent spot with zero current in the wires and zero deflecting potential, then to turn on the current and observe the deflection for a given current, and finally, leaving the current constant, to turn on the deflecting potential and increase it until the spot is brought back to its original undeflected position.

Probably the most obvious way to use these observations is to get the velocity of the electron from the balanced electrostatic and magnetic deflections and then combine this with the observed deflection in the magnetic field alone to get e/m. Actually the measured deflection is the least accurate of the data and better results are obtained if it is ignored and the value of the accelerating potential is combined with the balanced deflection data to get the desired quantities. We will now describe in detail how this is done.

To simplify the calculations two assumptions are made that are quite closely realized in practice. The first is that the effect of the magnetic field may be neglected in the small region between the deflecting plates where the electric force is acting. The second is that all deflections are small; much smaller than shown in Fig. 2, which is distorted to make it easier to read.

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[1] Bainbridge, Am. Phys. Teacher **6**, 35 (1938).

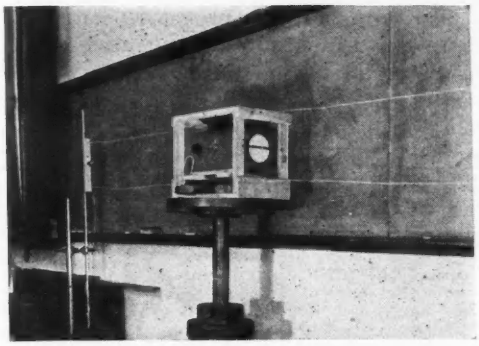

FIG. 1. Photograph of the mounted oscillograph.

Taking first the electric deflection, we see that the component of the velocity along the axis ADC is unaffected by the electric field perpendicular to it and remains equal to v, the initial velocity of the electron entering between the plates P and P'. If the length of the plates is L, the time spent between them by the electron is L/v. If E is the strength of the electric field between the plates, e the charge on the electron, and m its mass, there is a vertical force Ee which gives the electron a vertical acceleration Ee/m. Consequently, in the time the electron is between the plates, it acquires a vertical velocity EeL/mv. The ratio of the vertical component of the velocity to the horizontal component gives us the tangent of the angle θ, the direction in which the electron is moving when it leaves the plates; that is,

$$\tan\theta = EeL/mv^2. \tag{1}$$

Now taking the effect of the magnetic field into account, it is evident that the electron will travel in the arc of a circle FKC whose radius R is given by

$$Hev = mv^2/R, \tag{2}$$

where H is the magnetic field. Strictly speaking the velocity in this equation should be the total resultant velocity but if the electric deflection is small, as we have assumed, this can be taken equal to the initial velocity as we have done. If the electrons are to strike at C, the angle AOC must equal 2θ. But this angle is given by AKC divided by R. If the angle is small, the chord AGC may be substituted for the arc AKC; that is, $\angle AOC = 2\theta = AGC/R$. But $AD = L/2$ and $DC = d$, so that

$$2\theta = (L/2+d)/R. \tag{3}$$

Also, if θ is very small, $\tan\theta = \theta$, so that we get from Eqs. (1), (2) and (3),

$$2\theta = \frac{2EeL}{mv^2} = \frac{(L/2+d)He}{mv}$$

or

$$v = \frac{2L}{(L/2+d)}\frac{E}{H}. \tag{4}$$

In an ordinary oscillograph tube, L is about 1/20 of d so that $L/2$ can be neglected if we are only hoping for an accuracy of about 5 percent. Making this approximation we get

$$v = 2LE/dH, \tag{4'}$$

the expression we have actually used.

The quantities in these expressions are, of course, in absolute units. The electric field E is produced by a potential difference V applied to the plates P and P'. If s is the distance between them, $E = V/s$. The magnetic field H is produced by the currents in two straight wires each a distance r away, so each contributes an amount given by $2I/r$. Therefore the magnetic field acting on the moving electrons is given by

$$H = 4I/r,$$

where $2r$ is the distance between the wires. Substituting for E and H in Eq. (4'), we get

$$v = VLr/2Isd, \tag{5}$$

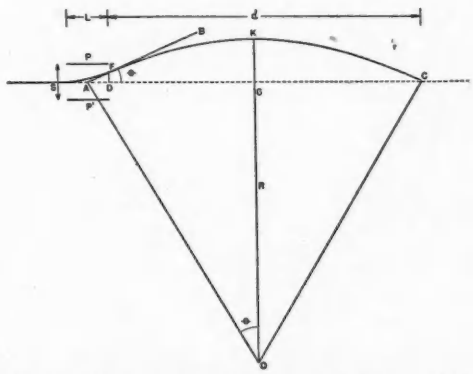

FIG. 2. Diagram showing the geometry of the method.

where all the quantities are in absolute units.

If V is measured in volts, I in amperes and all the distances in centimeters, this expression becomes

$$v=10^9VLr/2Isd \text{ cm/sec.} \quad (6)$$

The dimensions of the oscillograph are supplied by the manufacturer but can also be verified approximately by inspection. In the one we have used they are: $d=21.5$ cm, $L=1.25$ cm, $s=0.475$ cm, $r=12.5$ cm.

Typical values for zero resultant deflection obtained in lecture when V_a, the accelerating voltage on the electrons, was 330 v were: $I=8.00$ amp, $V=11.5$ v (average of two readings). Using these values in Eq. (6), one obtains

$$v=11.5\times1.25\times12.5\times10^9/(2\times0.475\times21.5\times8.0)$$
$$=1.10\times10^9 \text{ cm/sec.}$$

In order to get e/m we use the familiar relation between v and V_a, the accelerating voltage involving the mass and the charge of the electron, namely $V_ae=mv^2/2$ or $e/m=v^2/2V_a$. If V_a is in volts, m in grams and e in abcoulombs, this becomes

$$e/m=v^2\times10^{-8}/2V_a.$$

Substituting the foregoing values, we get

$$e/m=(1.10)^2\times10^{18}\times10^{-8}/660$$
$$=1.83\times10^7 \text{ abcoulomb/g.}$$

With the same oscillograph tube set up again for the experiment a year later, the values obtained were $I=7.9$ amp, $V=10.85$ v and $V_a=326$ v. These data give for e/m a value of 1.69×10^7 abcoulomb/g. The accepted value is 1.75×10^7 abcoulomb/g.

Appointment Service

REPRESENTATIVES of departments or of institutions having vacancies are urged to write to the Editor, Columbia University, for additional information concerning the physicists whose announcements appear here or in previous issues. *The existence of a vacancy will not be divulged to anyone without the permission of the institution concerned*

20. Ph.D. Univ. of Minnesota; S.B., S.M., M.I.T.; 1 yr grad. work, Univ. of Iowa. Age 38, married, 2 children. 17 yrs teaching experience in universities, colleges and technical schools, including 10 yrs head of department. Interested in progressive undergraduate and graduate teaching and research, including mathematical physics.

21. M.S. Kansas State. Age 38, married, 2 children. Research, acoustics. Experienced in laboratory maintenance, design and construction of apparatus, and writing of manuals. Desires teaching or industrial laboratory employment.

22. Ph.D. Univ. of Illinois; A.B. Wabash College. Age 31, married, 2 children. Has taught 4 yrs in liberal arts college and 1 yr in large state university. Co-author, laboratory manual. Interested in college or university teaching, laboratory development, and research. Available, fall 1938.

23. M.S., B.S. Louisiana State Univ. Age 24, unmarried. 2 yrs teaching fellow, physics; 2 yrs practical engineering experience; 2 summers, seismic prospectings. Desires teaching or industrial laboratory position.

24. Ph.D. Age 32, married, no children. Experience: 4 yrs secondary school; 4 yrs instructor, state university; 3 yrs head of physics and mathematics, liberal arts college. Author, laboratory manual. Two research grants. Desires position in larger college or university.

25. Ph.D. Yale. Age 33, married, 2 children. Industrial research experience; 3 yrs instructor in small college. Interested in teaching in coeducational or mens liberal arts college. Available June 1938.

26. Ph.D., with long experience in an American college in China, wishes a college teaching position.

27. Ph.D., physics, Northwestern '35; A.B., engineering, Harvard. Age 42, married, 3 children. Experience: 1 yr, lt., artillery; 12 yrs business and sales; 5 yrs college teaching. Interested in undergraduate teaching, including astronomy.

28. B.S. in E.E., M.S., physics, Dr. Phil. Nat. from German univ. (Exchange fellow from U. S.) Age 32. 7 yrs teaching experience in advanced courses and physics for engineers.

29. Ph.D., Northwestern; M.S., Pittsburgh; A.B., Muskingum. Age 34, married, 1 child. Has had 13 yrs teaching experience in two universities. Interested in teaching and research.

Departments having vacancies or industrial concerns needing the services of a physicist are invited to publish announcements of their wants; there is no charge for this service.

Any member of the American Association of Physics Teachers may register for this Appointment Service and have a "Position Wanted" announcement published without charge.

DISCUSSION AND CORRESPONDENCE

Temperature and Difference of Temperature

A FEATURE relating to the conversion of temperature from one system to another, which was a source of discontent some years ago, was that involved in writing the equation

$$180°\text{F} = 100°\text{C}. \quad (1)$$

The discontent was not lessened when, as was not unusual, one saw on the board at the same time the equation

$$212°\text{F} = 100°\text{C}, \quad (2)$$

an equation which seems correct, and able to stand without apology.

Obviously, Eq. (1) cannot stand by itself, and needs an apology. The suggestion of how to overcome the difficulty was first made by Dr. Forrest Western of Lincoln Memorial University when a graduate student at our institution. The suggestion is that we use °F or °C when referring to a *temperature* and F° or C° when referring to *difference in temperature*. With this convention, Eq. (1) becomes, instead,

$$180\text{F}° = 100\text{C}°. \quad (3)$$

It would be read, "180 Fahrenheit degrees equal 100 centigrade degrees," as I believe is the general practice when the intent is to equate temperature differences.

Consider the simple problem of finding the centigrade equivalent of 95°F; the solution is, evidently,

$$T = 0°\text{C} + (95°\text{F} - 32°\text{F})(5\text{C}°/9\text{F}°) = 0°\text{C} + 35\text{C}° = 35°\text{C}.$$

Next consider the equation involving the specific heat of a substance, 100 gm of which at 100°C introduced into 200 gm of water at 20°C raises the temperature of the water to 40°C; it is

$$100 \text{ gm} \times c \times 60\text{C}° = 200 \text{ gm} \times 1(\text{cal/gm C}°) \times 20\text{C}°.$$

University of Pittsburgh,
Pittsburgh, Pennsylvania. A. G. WORTHING

An Elementary Experiment on Mechanical Advantage

ALTHOUGH the adaptation of the motor-driven rotator to an experiment on mechanical advantage is a rather obvious one, I have seen no mention of it, and hence, hope that the idea may be helpful to those interested in the elementary laboratory.

The rotator commonly used for the experiment on centripetal force (e.g., Cenco No. 74350 friction drive, variable speed rotator) is a convenient device to illustrate power transfer by belts and gears. The ideal mechanical advantages of the pulley combination and of the friction wheel-disk combination may be found from measurement of the effective radii, and also from the speeds of rotation.

In the case of V-shaped grooves the effective radius may be considered to be the distance from the center of the wheel to the center of the bright band worn in the groove by the belt. A vernier caliper, a Veeder revolution counter, and a watch are the only accessories needed. Each method of measurement gives data from which the total mechanical advantage may be found. The student is able to obtain values that differ by 5 percent or less, if reasonable care is taken in measuring the radii.

Montana State College,
Bozeman, Montana. A. R. JORDAN

A Hydrostatic "Paradox"

UNTIL recently it seems to have been the custom in presenting the subject of hydrostatics to students of general physics to start by confusing them with a "paradox." *The* Hydrostatic Paradox, as it was called, referred to the fact that the pressure in a liquid is a function of its depth regardless of the shape of the containing vessel. It has, doubtless, been the experience of many teachers that it was necessary to explain not the "paradox," but why the phenomenon was referred to as a paradox in the first place. It is refreshing to see that a number of the more recent textbooks have refrained from mentioning the word paradox.

For those who still like to talk about paradoxes to their students, an elementary experiment will be presented which will probably serve the purpose. The aim of this discussion is really not the presentation of a peculiar phenomenon. Instead, it is hoped that it will suggest a better approach to Archimedes' principle. The premise on which these words are written is that very few students ever learn anything about Archimedes' principle other than that a body immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced. It is believed that many of us have let the thing go at that without showing clearly the fact there is a difference in pressure which gives rise to the buoyant force.

And now for the paradoxical experiment, which is probably so old that some of us never heard of it. Consider, for simplicity, a uniform cylinder whose density is one-half the density of mercury. This cylinder immersed vertically in mercury will sink until half of its volume is under the surface of the mercury. The cylinder will "displace" a volume of mercury equal to half the volume of the cylinder.

Suppose that the cylinder has a radius r and that its height is $2h$. It "displaces" a volume of mercury equal to $\pi r^2 h$. Assume, however, that the mercury is contained in a beaker whose inside radius is R. The cylinder will still sink to a depth h and the minimum volume of mercury required to float the cylinder is $\pi(R^2 - r^2)h$. But if R is made nearly equal to r, the cylinder "displaces" many times the actual volume of mercury that we have on hand. The answer is, of course, obvious. The experiment can be demonstrated with any cylindrical weight, a beaker slightly larger in diameter than the weight, and a little mercury.

The idea of floating large bodies in a small amount of mercury has been used many times in practice in floating interferometers, telescopes, etc.; so there is nothing

novel about the experiment suggested. Nevertheless, this whole trivial consideration may encourage some of us to stress more the fundamentals in our teaching of Archimedes' principle rather than to permit the students to learn a sequence of words without fully understanding their meaning.

Duke University,
Durham, North Carolina.

J. C. MOUZON

James Watt and Graphs

IN the current issue of *Osiris*,[1] a periodical seldom seen except by specialists in the history of science, is an article by H. G. Funkhouser on the early use of graphs in the presentation of statistics, the first twenty pages of which will interest some physicists.

The earliest suggestion of the concept of functionality in natural phenomena Funkhouser finds in a manuscript of the philosopher Nicole Oresme about 1350, and follows it down through the years to 1786, when it makes a sudden, dramatic entrance into the field of the social sciences in a book by William Playfair, *The Commercial and Political Atlas*, containing 44 charts very modern in aspect. The matter is mentioned here because of the interest attaching to the circumstances to which his use of the method is ascribed. His older brother, the mathematician John Playfair, had taught him that "whatever could be expressed in numbers might also be represented by lines," and had required him to keep thermometer observations in this form. This would seem sufficient explanation since all but one of the charts show simply year-to-year fluctuations of some phase of British trade. But also, beginning in 1780, he had served as draftsman in the shop of James Watt, who has been elsewhere noted[2] as practically the first to use graphs for other than chronological sequences of data, and that in 1782. One may only speculate as to the kind of intellectual collaboration that went on in this shop where certainly more than steam engines were evolved. Was it, as Funkhouser assumes, the lively genius of Watt that inspired Playfair, or have we here in the Playfairs the specific means by which the germinant idea was planted in the fertile mind of Watt?

The *Atlas* had a conspicuously more favorable reception in France than in England, and Funkhouser expresses the opinion, encountered likewise in other connections, that there was "greater activity in graphic work for the next century" in the country of Descartes than elsewhere.

Princeton University Library,
Princeton, New Jersey.

MARGARET C. SHIELDS

[1] Osiris **3**, 268–404 (1938).
[2] Am. Phys. Teacher **5**, 68–71 (1937).

Unfair Competition in the Consulting Field

THE Association of Consulting Chemists and Chemical Engineers, Inc., has released for publication a report drawn by its Committee on Professional Welfare which deals with various forms of unfair competition in the consulting field. That part of the report which may be of particular interest to college and university physicists is summarized below.

The fundamental purposes of universities and colleges are the creation, organization and dissemination of knowledge, and the development of young people for the needs of society. These functions are exercised for the benefit of the world at large. Educational institutions are supported in a large measure by taxes and benefactions, and are largely tax-exempt. It is consistent with these purposes and with the circumstances of their support for educational institutions to conduct fundamental research for the advancement of knowledge.

It is inconsistent with these purposes and improper in view of the nature of their support for educational institutions: (a) to render services to private interests for commercial purposes; (b) to permit the name and prestige of the institution to become involved in consulting work undertaken by members of the staff, or to allow the use of its facilities for such work without adequate charge; (c) to become involved in competitive activities which may restrict the opportunity for graduates of such institutions to practice the professions for which they were trained.

As a criterion which can be simply stated and easily applied, the Association suggests that research, analysis and testing service carried on by educational institutions should be limited to purposes which are in the interest of the public at large and which do not accrue advantageously to private interests through patents or otherwise. The results of such activities should generally be made available through reasonably prompt publication.

The report also deals with activities by government bureaus and agencies, and scientific work done by manufacturers under the label of "sales service," insofar as these touch the field of work of independent consultants and laboratories. Copies of the complete report may be had upon request to the Association.

LOUIS WEISBERG, *Chairman*
Committee on Public Relations

Association of Consulting Chemists and Chemical Engineers, Inc.
50 East 41st St.,
New York City.

A Plea for Two Changes in Textbooks

MOST of us, I dare say, enjoy looking over new textbooks. We open each one with the hope that at last the one we have been looking for has been written. We turn its pages quickly to get a general impression, and then more carefully look up some special subjects in which we are particularly interested.

One pleasing change in many recent books is the use of new illustrations and diagrams; one gets tired of seeing the same old cuts even if the apparatus is not obsolete. It is often with a feeling of disappointment, however, that one sees repeated in text after text methods of presentation which also need new life. Two cases in particular I should like to mention.

The first deals with the laws of reflection and refraction. Many texts say for reflection, "The angle of incidence is equal to the angle of reflection." To my notion this should at least be stated the other way around. Moreover, few texts mention the plane in which the reflected ray should appear.

Now, since it is important to bring out the basic law that the path of a ray of light is reversible, would it not be better to say,

The incident and reflected rays make equal angles with the normal to the surface, at the point of incidence, and the two rays and the normal lie in one plane,

or something of the sort?

Again, most texts state the law of refraction about this way: "The index of refraction is equal to the sine of the angle of incidence divided by the sine of the angle of refraction." Yet, the student, in working problems, is confronted with many cases, such as the passage of light from water into glass or from glass into air, where either the meaning of "index of refraction" or the meanings of "incidence" and "refraction" must be changed.

Again, the plane in which these rays are found is seldom mentioned. Would it not be better to say something like this:

When a ray of light passes from medium 1 into medium 2, the paths in the two mediums and the normal to the surface separating them are all in the same plane, and the angles the rays make with the normal are related by the expression

$$n_1 \sin \theta_1 = n_2 \sin \theta_2? \qquad (1)$$

Here n_1 and n_2 are the indices of refraction of the two mediums, and θ_1 and θ_2 are the angles the rays make with the normal.

If we agree to call the index of refraction of air unity, then Eq. (1) can be used to define the index of refraction of any other medium. This would allow n to keep the same meaning at all times and that meaning would agree with the values given for it in handbooks and tables of constants.

Equation (1) is perfectly general, applies to all cases, and is no harder to learn than the one usually presented. For the special case of a ray passing from air or vacuum (where n can be taken as unity) into a denser medium, it reduces to the more usual form. And since n_1 and n_2 are constants, the ratio of the sines of the angles is a constant, this being Snell's law. But, in its general form, it is much more powerful and less confusing to work with. Also, the reversibility of light path is implied, as nothing is said about which is the incident and which the refracted ray. For parallel layers of material of different optical density, it leads to the expression

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 = n_3 \sin \theta_3 = \cdots,$$

which shows at a glance that the angle in the final medium is independent of all the layers between. The case of atmospheric refraction is one example of this, but there are many more.

The second suggestion I should like to make deals with the classification of spectra. It is true, of course, that the obvious types of spectra encountered in the general course and most easily distinguished from each other are "bright line," "continuous," and "absorption," with the usual meanings attached to these terms. However, this division suggests to the beginner that they are three classes in the same category. This, I feel, is a mistake. Classified one way, all spectra are either *emission* or *absorption*. Classified another way, they are *lines* (due to atoms), *bands* (due to molecules), or third, more or less broad *continuous regions*.

Would it not be possible to introduce the student at once to the two main classes, *emission* and *absorption*, and then subdivide each of these into *line*, *band*, and *continuous*, or just *line* and *continuous*, as one preferred? While it would mean a trifle more for the student to learn, his first impressions would be correct and not lead to confusion or call for a revision of thinking when he began to study the origin of spectra.

Teachers and writers have their own preferences, and often good reasons for them, but I feel that we frequently pass on a thing as we learned it or as we find it in most texts because that is the easiest, though not necessarily the best, way of doing it. This is more likely to be the case in a general course, where the student and the rest of us are likely to be the slaves of the printed page. The way a subject is developed or presented in his text, the student feels must be the best way. He knows the instructors make mistakes, so how can he be sure they know better than his text? And, anyhow, if he loses his notes, he goes back to his text even if he saw the point at the time the matter was presented in class. So, for all our much talking, the textbook always wins. I plead, therefore, for at least these changes in the textbooks.

Rouss Physical Laboratory,
University of Virginia,
Charlottesville, Virginia.

FREDERICK L. BROWN

Where is a Fish Seen?

IN the February issue appears a letter from Professor Laird[1] entitled "Position of the Image of an Object Under Water," in which she gives expressions for the vertical and lateral displacements of an under-water object, as seen obliquely by an eye situated above the water level. Professor Laird's formulas are, of course, quite correct. But there is more to this problem than at first appears, for it can be shown that the image of a fish, *as it is usually perceived*, is directly above the real fish, without any lateral displacement.

This apparent paradox results from the fact that the image of a submerged object is, in general, astigmatic to a considerable degree. Professor Laird's formulas give the intersection of two neighboring rays only when these lie in a single vertical plane. On the other hand, a pair of rays in a plane at right angles to this intersect on the vertical line through the object itself. This fact is easily established from the consideration that everything is symmetrical about this vertical line, so that each incident ray and its refracted extension must lie in a vertical plane. For this reason a plumb line hung in water shows no apparent bending at the surface, as would a stick stuck in obliquely. In fact, the appearance of the submerged part of the line coincides exactly (as a line, not in its longitudinal detail) with the reflected image of the unsubmerged part.

Now, the pupil of the eye is so small that the astigmatism of a pencil of rays is not noticeable unless this astigmatism is very great, or unless a strong effort is made, as in reading, to focus sharply. But it happens that we have two eyes, and the common practice is to keep these in a horizontal line. For this reason, in viewing a submerged object, we align our two visual axes to meet at the focus for rays that lie in a plane at right angles to the plane of rays for which Professor Laird's formulas are given. The result is that we see

the image as lying directly above the object. It is true that our eyes are then incorrectly focused for rays in a vertical plane, but this fact is easily overlooked because of the small diameter of the pupil. If one were to turn his head to the side, so as to bring the two eyes into a vertical plane through the object, he would then be obliged to align them for rays that meet at the point given by Professor Laird's formulas.

The author of the present note has actually tried this with an object submerged in an aquarium. If this object is not too far away, one easily notices that, as he turns his head, the image seems to move closer. On looking into the *side* of an aquarium the roles of vertical and horizontal positions would, of course, be interchanged. If we were equipped with four eyes, in the pattern of a cross, we could hardly help noticing the astigmatism of these under-water images.

However, it is only for comparatively close objects that the convergence of the two visual axes supplies the principal basis for judgment of distance. For distances greater than a few feet this criterion becomes rather inaccurate, and distance-judgment is a complicated intuitive mental process based on such data as the linear dimensions of the object—if these be already known—or the spatial distribution of such other objects as happen to be in the field of view. For objects either above us in the air, or situated in a large body of water, frequently there are no other objects conveniently located for comparison, and when this happens our distance-judgment becomes very uncertain. Sometimes, in these circumstances, one instinctively moves his head about, in order to compensate for the fact that a pair of eyes are set too close together to act efficiently as a range-finder for any but short distances. If, in such a case, the head were to be raised or lowered, one might readily come to the conclusion that a fish was in the position given by Professor Laird's formulas, despite the reasons given here for locating it directly above the actual position of the real fish.

HERBERT M. REESE

University of Missouri,
Columbia, Missouri.

[1] Am. Phys. Teacher **6**, 40 (1938).

PROFESSOR Reese has done a service in calling attention to the existence of two focal lines when a pencil of light from a point under water is refracted, so that the caustic (the coordinates of a point of which are given in my note) should include the line drawn from the apex normal to the surface. I should like to corroborate his observation that using *two* eyes in a vertical line one sees the nearer focus, and that it is in general easier to see the one in the same vertical line as the object when the *two* eyes are in a horizontal line. Experience, the surroundings, and the nature of the object also influence one's impressions of position. Even if a stick is put into water obliquely, frequently it will not look broken as viewed from a point in the plane containing the stick and the normal at the point of immersion, unless the surface of the water is clearly visible as a reference point. On the other hand, I might report the following case. When rowing on a mountain lake of very clear water and light sandy bottom, a companion called out in alarm that we were running aground. We appeared to be in a bowl of water, considerably deeper than an oar's length, but with rather steep sides. We apparently were seeing the bottom come towards us, as well as nearer to the surface.

ELIZABETH R. LAIRD

Mount Holyoke College,
South Hadley, Massachusetts.

Image of an Object Under Water

THE recent note by Professor Laird[1] does not emphasize certain essential features of the phenomenon. Some additional remarks appear desirable, particularly since this phenomenon is a good example of astigmatic images and can be demonstrated easily by lecture experiments.

A pencil of rays, emerging from the surface and reaching the eye, is obviously not homocentric and will give astigmatic images. A plane elementary pencil in a vertical plane will give an image in the place calculated by Professor Laird. A plane elementary pencil in a plane normal to the former plane will give an image situated on the normal from the object to the surface, at a depth that can be calculated in the usual manner. With regard to the pencil that really reaches the eye or instrument, each point of the object will have, as an image, two small lines, one in each of the above mentioned places. These lines are normal to each other; the distance between them is the *astigmatic difference*. In consequence of this, the last mentioned image, or that on the normal from the object to the surface, will give sharp images of vertical lines in the object. The former image, or that nearer the eye, will give sharp images of horizontal lines in the object.

I generally give a demonstration of this in the following way. A small glass plate, ruled with horizontal and vertical lines, is placed in vertical position in a glass vessel containing water. The image is observed through a microscope with an objective of large focal length. The object is illuminated with monochromatic light from a sodium lamp. With the microscope in one position, vertical lines in the image will be sharp; in another position, horizontal lines will be sharp. The distance along the axis of the microscope between these two positions is the astigmatic difference.

An approximate measure of the displacement of the microscope along the axis, when the angle between the emerging pencil and the water surface was about 45°, and the depth of the object below the surface was 30 mm, gave 8 mm as the astigmatic difference, which is in accord with the formulas cited.

GUSTAF ARVIDSSON

Tekniska läroverket Malmö,
Sweden.

[1] Am. Phys. Teacher **6**, 40 (1938).

RECENT PUBLICATIONS AND TEACHING AIDS

Reference Books

Elasticity, Plasticity and Structure of Matter. R. Houwink, plastic department, N. V. Philips Gloeilampenfabrieken, Eindhoven, Holland. 394 p., 214 fig., 40 tables, 13×21 cm. *Cambridge Univ. Press*, $6. The three groups most interested in the elastic and plastic phenomena which accompany deformation of matter are the physicists, the chemists, and the scientific technologists, and one of the purposes of the present book is to make it possible for these groups to understand one another more easily and, by the aid of an insight into the structure of matter, to seek greater improvement of existing materials and to discover new ones. Although unity of thought is seldom encountered in the literature of the subject, the author has attempted to trace such unity as far as it exists. Thus he has compared the observations on such very different substances as glass, resins, asphalt, rubber, sulfur, crystalline substances, etc., and has examined the extent to which the known general laws for deformation actually correspond to these observations. Although the results were often disappointing, either because of lack of data or of sufficient insight into the structure of the substances, in many other cases it was found possible to make reliable prophecies about the behavior of a material upon deformation on the basis of its structure. Herein, believes the author, lies the key to the deliberate synthesis of materials with definite desired elastic and plastic properties, which will be carried out in the coming decades. One has only to think of artificial rubber and wool, he reminds us. The chapter in the book which surveys the present knowledge of the plasticity of crystals was prepared by W. G. Burgers.

Survey Courses

What About Survey Courses? Edited by B. Lamar Johnson, librarian and dean of instruction, Stephens College. 388 p., 2 fig., 12 tables, 13×21 cm. *Holt*, $2.85. A group of twenty-eight educators working on survey course developments in various colleges and universities have cooperated in preparing this book. Three chapters are devoted to general aspects and problems, twelve to curriculums in specific institutions, three to natural science survey courses, six to survey courses in the social studies and humanities, four to the composite survey course, and one to measurement and evaluation. The chapters on the natural science courses were prepared by R. J. Havighurst, S. R. Powers, and F. L. Hovde. The definition of survey courses adopted for the book is that proposed by Havighurst [Am. Phys. Teacher **3**, 97 (1935)]; namely, ". . . any course intended for college freshmen and sophomores primarily as a part of their general education, which draws its subject matter from two or more of the ordinary college departments."

Miscellaneous Books

Scripta Mathematica Forum Lectures. 97 p., 8 fig., 13×18 cm. Yeshiva College, $1. Four lectures for laymen on *Mind, the Maker—the World Theory of the Late William Benjamin Smith*, by Cassius Jackson Keyser; *The Story of Mathematics* (Historical development), by David Eugene Smith; *New Names in Mathematics* (Terminology), by Edward Kasner; and *Science in Relation to Social Growth and Economic Development*, by Walter Rautenstrauch.

History of Science

See the essay-review, "Scientists, Historians, and the History of Science," by John Pilley, on page 133.

Booklets

George Westinghouse Commemoration. 78 p., 55 photographs, 19×27 cm. *American Society of Mechanical Engineers.* This beautifully printed cloth bound volume on the career and engineering achievements of George Westinghouse will be sent gratis to college physics libraries upon request to the Technical Press Service, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa. The volume contains some 18 papers presented at a commemorative forum conducted by the American Society of Mechanical Engineers.

Eyesight and Corrections of Eye Defects. *Bausch & Lomb Optical Co.* (Rochester, N. Y.), gratis. Four nontechnical pamphlets, each 9×16 cm and 15–20 p., entitled *Your eyes and how they function, What you should know about your child's eyes, 45 years young* (on bifocal lenses), *Thirty-mile eyes in sixty-mile cars.*

Publications of Good Housekeeping Institute. *Good Housekeeping Bulletin Service* (57th St. at 8th Ave., New York), 3 cts. each. Each of the following bulletins is 10×22 cm and has approximately 12 pages: *Buying an automatic refrigerator, Buying a vacuum cleaner, Buying an electric ironer, Buying an electric range, Buying a gas range, Buying an electric heater, About automatic refrigerators, Safety in the home.*

Forthcoming and Recent Meetings on the Improvement of Physics Instruction

Toronto Meeting of the American Association of Physics Teachers, June 24–25

THE American Association of Physics Teachers will meet jointly with the American Physical Society at the University of Toronto on June 24–25. Registration will open on June 23, at 2:00 P.M., in the McLennan Laboratory.

The program will include liquid helium demonstrations in the cryogenic section of the McLennan Laboratory, a display of striking physics experiments arranged by the Toronto department in collaboration with the teachers in nearby secondary schools, a garden party given by the president of the university, and excursions to the David Dunlop Observatory and other places of interest. On Friday evening there will be an informal dinner for the members of the two societies at Hart House on the university campus. Those who will find it convenient to arrive on Thursday may wish to attend the weekly symphony concert given on Thursday evenings at popular prices in the university Arena.

Arrangements have been made to have breakfast and luncheon served at Hart House during the meetings, at a cost of 50 cts. per meal. Some 225 rooms for men or women, and 50 double rooms for married couples, will be available in student residences from Thursday afternoon until Monday morning at a cost of $2 per person for the first night and $1.25 per person for each succeeding night. For reservations, address Professor J. O. Wilhelm, Department of Physics, University of Toronto, Toronto 5, Canada.

San Diego Meeting of the American Association of Physics Teachers, June 24, 1938

THE first Pacific Coast meeting of the American Association of Physics Teachers will be held in San Diego, California, June 24, 1938, in connection with the 22nd annual meeting of the Pacific Coast Division, A. A. A. S. and Associated Societies. Balboa Park will be general headquarters for all the meetings.

The following invited papers will be heard at a session beginning at 1:30 P.M.:

Mathematics in the Secondary School as Related to College Physics. PAUL S. EPSTEIN, *California Institute of Technology.*

Relation of the Cyclotron to Present-Day Courses in College Physics. E. O. LAWRENCE, *University of California.*

The Flying Laboratory. A. A. KNOWLTON, *Reed College.*

Equations of State for Physics Teachers. W. P. BOYNTON, *Oregon State College.*

The Physics Problem in High Schools. ROY W. MCHENRY, *Escondido High School.*

A program of 10-minute contributed papers is also being arranged.

The American Physical Society will hold five sessions at San Diego on June 22 and 23, and the morning of June 24. Other events of interest to physicists include the following A. A. A. S. lectures:

Recent Instrumental Developments in Astronomy. J. A. ANDERSON, *Mount Wilson Observatory.*

Recent Advances in Our Knowledge of the Oceans. H. U. SVERDRUP, *Scripps Institution of Oceanography.*

The local program committee for the Association consists of H. A. Kirkpatrick, Occidental College; R. R. Tileston, Pomona College; and L. E. Dodd, *Chairman*, University of California at Los Angeles.

University of Iowa Colloquium for College Physicists

The following program of invited papers has been arranged for the Colloquium for College Physicists which will occur at the University of Iowa on June 16–18.

Electron Emission. PAUL L. COPELAND, *Armour Institute of Technology.*

New Uses of Surface Effects in Electron Emission. PAUL L. COPELAND, *Armour Institute of Technology.*

Physical Valence. A. ELLETT, *University of Iowa.*

A Stroboscopic Demonstration and High Speed Motion Pictures. NEWELL S. GINGRICH, *University of Missouri.*

Twenty-Five Experiments for Twenty-Five Cents. RICHARD M. SUTTON, *Haverford College.*

Mechanics of Rotation—A Demonstration Lecture. RICHARD M. SUTTON, *Haverford College.*

Physical Phenomena in Animal Life. J. H. BODINE, *Department of Zoology, University of Iowa.*

Physical Phenomena in Plant Life. W. F. LOEHWING, *Department of Botany, University of Iowa.*

Other features of the program are round table discussions at the luncheon and supper meetings, led by J. A. Eldridge and R. M. Sutton, exhibits of motion pictures and demonstration experiments, and an open house in the physics laboratories.

Joint Meeting of the College Physics Teachers of Illinois

The physics teachers of the area outside of Chicago met at the University of Illinois, Urbana, on November 6, 1937, and formed a Physics Teachers Club, with Professor L. I. Bockstahler, Northwestern University, Professor R. Ronald Palmer, James Millikin University, and Professor R. F. Paton, University of Illinois, forming a general committee on arrangements.

In the Chicago area a chapter of the American Association of Physics Teachers has been in operation for some time and, at the suggestion of the down-state committee, a joint meeting was arranged. This was held in the physics

department, University of Illinois, on Saturday, April 23, 1938, with R. Ronald Palmer presiding.

The program was as follows:

1. Introductory Remarks. F. W. LOOMIS, *University of Illinois.*

2. Recent Curricular Developments at the University of Chicago. T. A. ASHFORD, R. J. STEPHENSON, AND M. J. FERENCE, *University of Chicago.*

3. North Central Association Requirements. W. H. ELLER, *State Teachers College, Macomb.*

4. School Laws as They Affect the Preparation of Teachers of Physics. FRANK L. VERWIEBE, *Eastern Illinois State Teachers College.*

5. Requirements of the State Education Department and the University of Illinois as They Affect the Preparation of Teachers of High School Physics. O. L. RAILSBACK, *Eastern Illinois State Teachers College.*

6. Evaluation of the Physics Department in a High School. A. W. CLEVENGER, High School Visitor, *University of Illinois.*

7. Teaching Combinations for the High School Physics Teacher. R. F. PATON, *University of Illinois.*

8. News Notes from Other States. GLEN W. WARNER, *Woodrow Wilson Junior College.*

9. A Possible Division of the State for Effective Field Work. V. F. SWAIM, *Bradley Polytechnic Institute.*

The papers presented and the discussion that followed were of vital interest to all teachers present, especially to those who are interested in raising the standard of the teaching of physics in the high schools of the state. Professor Clevenger's paper on evaluation of the physics department in a high school left little or no doubt as to the proper setting that this important division of science should have in a modern high school. Many important phases concerning such matters as curriculums, teaching loads, procedures, and teacher preparation were brought out in the general discussion at the end of the program, which was led by L. I. Bockstahler.

Among the important recommendations made and adopted by the Joint Session was that sponsored by Professor Glen W. Warner, that a minimum of 16 hours of college physics be required of prospective high school teachers of physics. It was the feeling of the group that such a recommendation should not be immediately applied to teachers already in service.

The attendance was 32, with 21 colleges represented.

CHAS. T. KNIPP, *Secretary*
Illinois Physics Teachers Club

University of Illinois,
Urbana, Illinois.

Papers on Instruction in Physics Read Before the Southeastern Section of the American Physical Society, April 1–2, 1938

THE annual meeting of the Southeastern Section of the American Physical Society was held at the University of Alabama on April 1 and 2, 1938. Included on the program were the following papers and reports pertaining to instruction in physics.

1. The Problem of the Premedical Course. CLYDE B. CRAWLEY, *University of Alabama.*—Much of the resentment which premedical students in general have for physics could be overcome by designing a special course for them. The outline of such a course should be substantially the same as that of any other physics course, but (1) the time allotted to the individual subjects should be redistributed so as to stress those parts of particular interest to the medical profession, and (2) medical illustrations of the subject matter should be substituted for engineering illustrations wherever possible. A survey of a number of physics textbooks shows that even the general "arts" text is primarily an engineering text and practically not at all premedical in character.

2. Elementary Laboratory Apparatus for Instruction in the Principles of Radio. SANFORD C. GLADDEN, *University of Mississippi.*—A set of apparatus has been designed for a laboratory course in the principles of radio. It consists essentially of a Hartley type oscillator whose frequency may be changed from about 800 to 8000 kilocycle/sec., together with three resonant circuits employing, respectively, a straight-line frequency condenser, a straight-line wavelength condenser, and a straight-line capacitance condenser. Two types of tube testers, one having all meters and resistors permanently connected, are available for testing triodes. A mounted crystal detector with a potentiometer serves to furnish information for rectification curves. Most of the ordinary radio experiments may be performed with a fair degree of accuracy.

3. An Elementary Derivation of Stirling's Approximation for *N* Factorial. BERTRAND P. RAMSAY AND DUDLEY E. SOUTH, *University of Kentucky.* (By title.)

4. A Tricolor Mixing Device Using Small-Angle Prisms. CALVIN C. WARFIELD, *Woman's College, University of North Carolina.* (By title.)

5. Correlation of Placement Test Scores and Physical Science Survey Scores at the University of Georgia. E. H. DIXON, *University of Georgia.*—At the beginning of the fall quarter 1937, the Examiner of the University System of Georgia administered placement tests to the freshman class; at the end of the same quarter a large section of the freshmen completed Physical Science, Unit I, and took the State test on it. This paper deals with correlations between these physical science scores and various parts of the placement test scores.

6. Survey Courses in the Physical Sciences. G. F. BARNES, *Judson College.*—A physical science survey course should have three important features: orientation, coordination, and thorough preparation for further work. The student should become acquainted with the scientific procedure; that is, he should be taught to observe, classify, and correlate facts, to formulate hypotheses, to check theories, and to use theories to check observations and to predict the course of future physical events. The various subjects included should be taught in their proper relation to one another, and so integrated that the student can see the unity of this great cosmic universe and his relation to it. He should become acquainted with the atomic structure of matter and the laws describing the nature of chemical re-

actions as well as those governing the great forces of nature that are so vital to our economic life. Each part of the course should be taught by a specialist in that field. Whole-hearted and enthusiastic cooperation of all persons concerned is necessary. If a text is not used, the students should be provided with an outline or syllabus of the subjects covered.

7. Remarks on Some Elementary Physical Concepts. WALDEMAR NOLL, *Berea College.*—In undergraduate physics it is important that the students secure a thorough understanding of fundamental concepts. A study was made of the discussions of force, mass, inertia, temperature, and the states of matter as they appear in a number of undergraduate textbooks. The standard used for evaluation was the operational viewpoint. The part perception plays in forming a concept is mentioned by many authors but does not appear to be sufficiently emphasized. In building precise concepts of mass and force, we may start with the idea of force as a sensation experienced either in lifting matter or in changing the velocity of a body on a smooth, horizontal surface. With this raw quantitative concept of force, it then becomes possible to define and to measure mass dynamically. The original concept of temperature may start with some sensation such as "hotness." The liquid, gas, and vapor states are readily defined by use of Andrews' isothermals. Vague and physically meaningless statements such as "mass is the amount of matter in a body" or "a torque tends to produce angular velocity" should be avoided.

8. Economic Aspects of Physics. DANIEL S. ELLIOTT, *Tulane University.*—A brief outline is presented of some of the factors that influence the profession of physics, of the raw material with which physics works, and of its productive output in personnel, material, and ideas.

9. Visualization of Trigonometry for Physics Classes. L. E. MCALLISTER, *Berry College.*—In elementary physics it is often necessary to review trigonometry briefly. A simple mechanical device is described which aids in doing this in the shortest time and with the most visualization (McAllister, Sch. Sci. and Math., Oct. 1931, and Nov. 1932).

10. The Elementary Physics Laboratory at Louisiana State University. T. N. HATFIELD, *Louisiana State University.*—For the past five years much time has been given to organizing and developing the elementary laboratory at Louisiana State University as a unit. An effort has been made to have uniformity of instruction and, in particular, uniformity of grading in the various sections. With 14 laboratory instructors, 10 of whom are graduate assistants, it has been found that this can be accomplished by having a common examination for all sections and basing the section average on it. Other procedures which have also been of help in developing the laboratory are described.

11. Proper Student Training to Meet Industrial Needs in the South. A. R. OLPIN, chairman, Committee on Industrial Relationships.

12. Present Tendencies and Status of Physics in the Secondary Schools of the South. C. R. FOUNTAIN, chairman, Committee on Secondary School Relationships.

Abstracts of the papers presented that pertain to research will appear in *The Physical Review.*

FRANCIS G. SLACK, *Secretary*
Southeastern Section of the
American Physical Society

A. A. P. T. Subcommittee on Letter Symbols and Abbreviations

THE Subcommittee on Letter Symbols and Abbreviations of the American Association of Physics Teachers has completed its preliminary survey and is anxious to receive comments on the list which it has prepared. A mimeographed copy of the list may be obtained from the chairman, Harold K. Hughes, Bard College, Annandale-on-Hudson, New York, N. Y.

Central Scientific and Westinghouse Fellowship Awards for 1938–39

THE Central Scientific Company Industrial Fellowships for 1938–39 have been awarded to Nolan R. Best, Muskingum College, and Barton L. Weller, University of Denver. The successful candidates were chosen from a group of twenty applicants.

Five Research Fellows for work in fundamental science at the Westinghouse Research Laboratories during 1938–39 have been selected from a group of fifty applicants as follows: Robert O. Haxby, University of Minnesota; John A. Hipple, Princeton University; Sidney Siegel, Columbia University; W. E. Shoupp, University of Illinois; and W. E. Stephens, California Institute of Technology.

DIGEST OF PERIODICAL LITERATURE

Apparatus and Demonstrations

A method of simultaneously projecting two periodic curves on a cathode-ray oscillograph. F. E. Kennard; *J. Sci. Inst.* **15**, 106, Mar., 1938. Two wave forms—for example, current and voltage—can be projected simultaneously on the same screen with the help of apparatus that is available in most laboratories; namely, a polarized relay and a ringing magneto. The relay contacts are arranged to act a as two-way switch, with the fixed contacts connected to the current and voltage circuits, respectively, and the tongue connected to one of the deflecting plates of the oscillograph. The other plate of the oscillograph is connected to a point common to both circuits. Since synchronism between the action of the relay and the frequency ν of the supply for the wave forms is unnecessary, the relay may be actuated at any frequency below $\nu/2$. This can be readily done by means of a hand- or motor-driven magneto.

A simple demonstration model of a vibrating molecule. W. H. J. Childs; *J. Sci. Inst.* **14**, 141, Apr., 1937. A model of an acetylene molecule is made from masses and connecting springs, and held in a V-suspension of threads so that only the three axial modes of vibration can occur. The model is excited by a current of air directed on the center of one of the masses and interrupted by the mechanism shown in Fig. 1. The light metal chopper C swings in a gap in the air

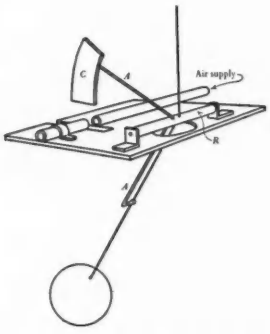

Fig. 1. The exciting mechanism.

tube. It is fastened rigidly by means of the bent arm AA to the rod R which is mounted in bearings. The pendulum bob is suspended by a thread that passes freely through both the rod R and the small hole in the arm A. The upper end of the thread is clamped to a scale and the pendulum can be varied continuously in frequency while swinging by changing the height of the clamp. When resonance occurs with one of the normal frequencies, the model quickly picks up energy and starts to vibrate in the corresponding normal mode; the air current can then be stopped completely and the model continues to vibrate undisturbed. In previously described models [Kettering, Shutts, and Andrews, Phys. Rev. **36**, 531 (1930); F. Trenkler, Physik. Zeits. **36**, 162 (1935)] excitation is produced by a solid connection, such as a rubber band; this is unsatisfactory because the model is then coupled to the exciting mechanism and its true frequencies cannot be observed.

Graphical construction for a refracted ray. Dr-Ing. A. Bloch; *J. Sci. Inst.* **13**, 302, Sept., 1936. The construction "tool" consists of a piece of transparent paper or celluloid along the edge of which two distances NA and NB are marked (Fig. 1) such that $NA/NB = n$, the refractive index.

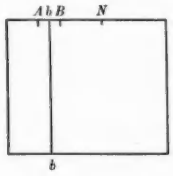

Fig. 1. The "tool."

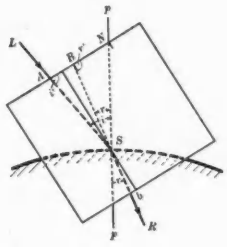

Fig 2. Construction of refracted ray.

The perpendicular bisector bb of AB is also drawn. To find the refracted ray, draw on a sheet of paper the refracting surface, the incident ray LS, and the normal pp to the refracting surface at s (Fig. 2). Then place the "tool" over this drawing so that N lies on pp, A on LS, and the perpen-

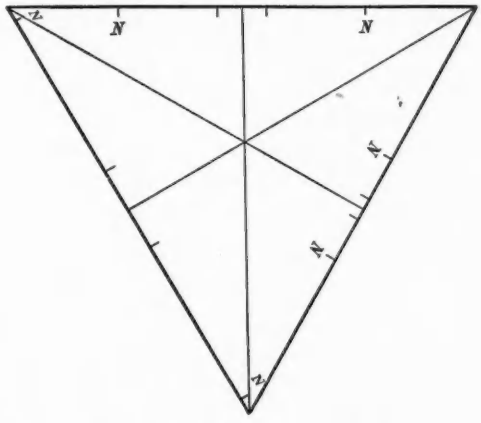

Fig. 3. Celluloid triangle, for $n = 1.5$.

dicular bisector b passes through s. The refracted ray is SR, which is BS produced.

To avoid reversing the "tool" (for rays incident on the other side of the normal) point N should be marked on either side of the perpendicular bisector (Fig. 3). In Fig. 3, the pattern of Fig. 1 is drawn on the three edges to different scales, selected to cover conveniently the range of angles of incidence 10–90°. The tool is usually not needed for angles under 10°, for then $r \sim i/n$.

The Three-Body Problem

Some recent results in the problem of three bodies. H. E. Buchanan; *Am. Math. Mo.* **45**, 76, Feb., 1938. The famous three-body problem of classical mechanics can be stated very simply. *Given* three rigid spherical bodies of specified masses, homogeneous in concentric layers, subject to no forces except their own attractions as described by the Newtonian law of gravitation, situated in arbitrary positions, and moving with arbitrary velocities at any time t_0, *find* the orbit of each body and the position of each in its orbit at any future time. Newton attacked the problem with his general theorems on the motion of the center of mass and by giving the first discussion of perturbations (*Principia*, Bk. I, Sec. XI). Lagrange found the first particular solutions of the problem, these being the celebrated straight line and equilateral triangle solutions. Other names associated with the problem include Euler, Laplace, Jacobi, Gauss, Poincaré, Hill, Moulton, Levi-Civita, and Sundman. "The problem of three bodies is not yet solved as thoroughly and completely as we wish but after all it is only about 250 years old!"

Some interesting results obtained in the last 10 years are described briefly in this paper.

Physical Sciences in Liberal Education

The contribution of the physical sciences. H. N. Holmes; *Bull. Assoc. Am. Coll.* **23**, 67–72, Mar., 1937. This article, one of a series on "Contributions to Liberal Education in the College," develops the idea that study in the physical sciences is cultural in the highest degree, particularly if it is continually associated with the social implications of scientific discoveries and inventions, and their effects upon the developing history of mankind. Important effects which should follow upon well-taught courses in physical science are: stimulation of creative imagination; development of honest attitudes in the search for truth; respect for law and order in the universe; the unification of knowledge, the desire to help humanity in learning to control natural phenomena.

Need Courses in Education be Superficial?

A serious charge. W. W. Charters; *J. Higher Ed.* **8**, 351–7, 1937. The author, who is editor of the *Journal of Higher Education* and director of the Bureau of Educational Research at Ohio State University, agrees in part with those professors in liberal arts colleges "who maintain that the mastery of subject matter is a sufficient training for teachers and that courses in education are chiefly thin collections of methods of instruction and administration which can normally be picked up on the job by the average teacher." He asserts, however, that this situation need not exist; that if courses in education are bodies of superficial methods, it is the error of educators, but not the fault of education.

Education, like the other professions, has its unique and basic bodies of materials; its special field is a knowledge of the human mind, particularly the minds of young people. it is unfortunate that while a medical student spends 75–125 semester hours on the anatomy, physiology, and pathology of the human body, a teacher-in-training devotes only 6–10 hours on pure and educational psychology which deals with the anatomy, physiology, and pathology of the human mind. It is unfortunate that educators consider an understanding of the human mind of such slight importance; the need is vital but they have not yet recognized it. Education is neglecting its fundamental bases. There is available today a huge body of materials in contributing fields which can easily be assembled for the required use of teachers, a body of knowledge without which teachers are less well equipped than are the nurses in the medical profession. The training of teachers cannot by any stretch of imagination compare with that of the physician, and this in spite of the fact that human psychology is more complicated and needs more artistry than human physiology.

Graduate Assistants as Teachers

Advice to the graduate assistant. A. D. Campbell; *Am. Math. Mo.* **45**, 32–3, Jan., 1938. At Syracuse University the department of mathematics has found certain measures and advice of value in helping young graduate assistants to make as few mistakes as possible during their first years of teaching. Assistants visit the classes of more experienced teachers and observe, and the latter visit the assistants' classes and criticize. Conferences of all who teach a given course are held. Tests for the courses are often made out at these conferences. The assistant is told not to talk too much in class, not to assign too long lessons, not to lecture, not to hide his work at the blackboard by his body, not to copy any other teacher's method slavishly, not to have a set method but to be flexible in his teaching. He is told to read his text, to plan his assignments, to show his tests to a more experienced teacher before he gives them, and he is given much other specific advice of a similar character. Above all, the assistant should be led to feel that teaching is a natural, friendly, helpful procedure that requires patience, much repetition, and no haste. He should make his students feel that he is interested in them personally. He should be helped to realize that knowledge of his subject, enthusiasm, friendliness, commonsense, and personality are what go to make up a good teacher.